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OPINION

TUTORIAL

GOVERNMENT TRANSFORMATION AND STRUCTURAL RIGIDITY: *REDESIGNING A SERVICE ACQUISITION PROCESS*

Dr. Ned Kock

Organizations have been increasingly pushed into a fast pace of change by the globalization of the economy, the accelerated technological developments in information storage and retrieval, and the emergence of knowledge (as opposed to capital goods) as the main asset of organizations. Many radical change approaches have been developed to ease this transition. While these approaches sometimes succeed, in most cases they fail miserably—a phenomenon that has been usually blamed on poor change management. The author argues that structural factors are also to be blamed, particularly process rigidity caused by highly functional heterogeneity, fragmented expertise, and government regulation. This point is supported by the analysis of a re-engineering attempt of a core process of a public sector organization in Brazil. The author proposes a simple framework to identify process structural rigidity in public sector organizations, and provide the basis to understand how structural rigidity can oppose radical change.

Organizational processes today are markedly different than they were 100 years ago. It has been estimated that in 1880 about 9 out of 10 workers produced and moved tangible, material things. In the mid-1990s this ratio was down to one out of five. The other four out of five workers currently produce and deliver intangible products such as information, computer software, and services (Drucker, 1993).

The accelerated development of new technologies, combined with the increasing globalization of the economy, has helped shape a global market in which organizations can have access to tools that make their processes efficient and effective anywhere in the world. So for most products generated and transferred within and between organizations today, whose soft elements (i.e., information, software, and service) can be delivered virtually in-

dependently of physical distance, fierce competition on a global basis has become commonplace.

To survive in such an environment, several organizations have had to become "virtual organizations," in the sense that they have come to chiefly depend on knowledge and process flexibility to generate and deliver products on a competitive basis (Davidow and Malone, 1992; Mowshowitz, 1997). Capital goods are no longer such a strategic advantage to organizations as process-related knowledge is, a reality that is reflected in the often high market valuation of knowledge and other intangible assets (such as computer systems) as opposed to material organizational assets such as production machinery and factory buildings (Strassman, 1996; Toffler, 1991).

Organizational flexibility, as well as the accumulation and proper deployment of process-related knowledge, depend on structural characteristics of organizations such as departmental and functional configuration, hierarchical levels, and information access and flow (Argyris, 1977; Redding and Catalanello, 1994; Senge, 1990). Hence, it is surprising to see the current focus on change management in process-based organizational transformation efforts (Kettinger and Grover, 1995; Stoddard and Jarvenpaa, 1995), and the relative lack of interest on structural factors that themselves can prevent organizational change from happening.

Here we describe a re-engineering attempt in a public sector organization in Brazil, particularly regarding the attempt to redesign one of its core processes—a service acquisition process. This provides the basis for our subsequent discussion of structural factors that can prevent radical process-based change projects from achieving successful results. The focus of this discussion is on process rigidity in public sector organizations, and its relationship with process functional heterogeneity and degree of government regulation. These factors are defined from a process-centered perspective, and their link with knowledge specialization is established. We conclude with a comparison of our case and other cases in the literature, and derive implications for public sector organizations interested in (or already) conducting process-based radical change projects.

Radical Change's Failure: Blame It On Bad Management!

The movement in favor of radical process-based change leveraged by information technology known as re-engineering begun in 1990 with two seminal articles by Thomas Davenport and James Short (1990), and Michael Hammer (1990). Having gone beyond its initial phase of optimism, which reached its peak in the two years following the publication of the

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book *Reengineering the Corporation* authored by Hammer and Champy (1993), the re-engineering movement entered a crisis stage (Deakins and Makgill, 1997). It was argued that re-engineering had led to heightened worker stress and lack of process outcome quality in a number of organizations where it had been implemented (Burke and Peppard, 1995; Economist, 1996; Labich, 1994; Willmott, 1995). Disagreements in the mid 1990s between what many saw as the main forefathers of the re-engineering movement, Michael Hammer and James Champy, worsened the crisis. While Hammer has continued to focus on techniques to radically improve processes (Hammer and Stanton, 1995), Champy pointed out that re-engineering success would not likely be achieved without a radical change in management paradigms (Champy, 1995).

Much has been published about reasons why re-engineering attempts may fail, as well as about success factors in re-engineering (both types of account highlight essentially the same, as success factors can be seen as factors whose presence is likely to prevent a re-engineering attempt from foundering). The reasons provided in the literature to explain why re-engineering so often fails have had a common focus—management. The literature generally suggests that re-engineering attempts are likely to fail if they lack top management support, which is often cited as the chief reason for failure (Archer and Bowker, 1995; Hall et al., 1993). It also highlights the importance of management selection and adoption of a structured methodology for process redesign (Guha et al., 1993; Wastell et al., 1994). Lack of understanding by management of what re-engineering really entails is also cited as a source of failure (Champy, 1995). King (1997) points out that since there is no universally accepted definition of organizational transformation, a notable source of failure in re-engineering is the confusion by management of incremental with radical process improvement. Top management leadership and strong involvement is singled out by Hewitt and Yeon's (1996) survey of United Kingdom companies engaged in re-engineering attempts as the main success factor in radical process-based organizational redesign.

"The literature generally suggests that re-engineering attempts are likely to fail if they lack top management support, which is often cited as the chief reason for failure."

Although re-engineering has been practiced in a variety of industries and economic sectors (Hewitt and Yeon's, 1996) with both positive (Bell, 1994; Caron et al., 1994) and negative results (Champy, 1995), little has been said about the influence of structural factors (i.e., those related to an organization's structure) on re-engineering success and failure. Can success factors be contingent on specific industry or economic sector characteristics? Or, more specifically, can certain characteristics of a specific industry or sector of the economy influence the structural rigidity of organizational processes—i.e. their structural resistance to change—so as to make re-engineering more likely to fail? The case study-based research discussed here suggests a positive answer to this question as regards one particular sector of the economy—the public sector. The case study on which the research was based is described next.

CASE STUDY: RE-ENGINEERING A SERVICE ACQUISITION PROCESS

Since the early 1990s, corporate Brazil experienced a growing interest in the adoption of voluntary quality standards; interest that was fed by a number of success stories (Ottoni, 1993). The most popular among these quality standards have been the ISO 9002, adopted by companies that produced goods or services based on third-party specifications; the ISO 9001, adopted by companies which developed their own products and services; and several versions of these two standards tailored for specific sectors and industries (Arnold, 1994; Voehl et al., 1994).

On the tail of the success of such orientation toward voluntary standards came a growing uncertainty about the need for government regulatory bodies and state-owned inspection companies in a number of industries. One such company was PubliCorp (pseudonym), a large civil engineering and construction services inspection company owned by a state government in Brazil. Among PubliCorp's main missions was that of enforcing government regulations in the construction industry.

"Pressed to become more competitive, PubliCorp set out in 1992 to re-engineer several of its business processes, including one of its core processes—the acquisition of construction services."

The prospect of deregulation pushed PubliCorp into considering moving from an enforcement role to, possibly, a quality consulting one. This would also force PubliCorp into a situation in which it would have to supply added-value services to construction companies, as it would no longer be able to deliver compulsory-purchase inspection services. As a consequence, PubliCorp's future survival would depend on the efficiency of its processes and the quality of the services delivered through them.

Pressed to become more competitive, PubliCorp set out in 1992 to re-engineer several of its business processes, including one of its core processes—the acquisition of construction services. As PubliCorp was a state-owned enterprise, the acquisition of services had to be made through the setting up and coordination of public bids, whereby PubliCorp was expected to select the most competitive contractors to carry out construction and maintenance jobs on public estate and transportation networks. This re-engineering project was seen by PubliCorp's top management and government officials as a test of the company's ability to compete in what some of them believed could in the future be a largely deregulated civil construction industry.

THE STAGES OF THE RE-ENGINEERING ATTEMPT

The research and normative literatures on business process re-engineering have identified a number of generic features that seem to be present in re-engineering attempts, whether these attempts fail or succeed to deliver the expected outcomes. Two of these generic features, both present in the re-engineering attempt at PubliCorp, are (Davenport and Stoddard, 1994): First is a focus on core processes that involve several departments or the whole organization. Core processes are defined (Kock et al., 1997) as those processes related to

the production and delivery of outputs to the external customers of the organization. Second is the use of information technology (IT) to enable the implementation of the new business processes devised through the re-engineering effort.

Another unfortunate characteristic of most re-engineering attempts has been a consistent failure to deliver the expected outcomes, of which the most important are a radical improvement in the efficiency of the processes redesigned or of the customer-perceived quality of the outputs of those processes. As far as failure rates of re-engineering attempts go, a widely cited figure is that obtained in a survey discussed by Champy (1995): Seventy percent or more of all re-engineering attempts fail to attain their goals. In this respect, the re-engineering attempt at PubliCorp was also typical in that it too failed to achieve its goals. The dynamics of this failure can be more easily understood by splitting the attempt into five main stages: problem definition and planning, IT infrastructure implementation, IT downsizing, core process re-engineering attempts, and process automation.

Stage 1: Problem definition and planning. Two small work groups with 10 to 12 members each (the number of members varied slightly along the whole attempt) were formed to tackle different issues in the re-engineering attempt. The IT group's main goal was to deal with the technical issues related to the setting up of an IT infrastructure to enable the re-engineered processes. The process redesign (PR) group was assigned the role of analyzing, proposing radical changes in the target business processes, and coordinating the implementation of these changes.

Re-engineering projects often start with the identification of urgent problems that are expected to be solved through radical process redesign (Hammer, 1996; Hammer and Champy, 1993). Two such problems were identified at PubliCorp regarding the process of acquisition of construction services: First was the centralization of data processing jobs in one department, largely due to the fact that product and service supplier databases were kept in a central mainframe computer operated by that department; second was the large number of "contact points" in the acquisition process, caused mainly by a disproportionate number of specialized tasks and control checks that had to be performed by employees with expertise in different areas (e.g., tax lawyers, construction budget experts, engineers specializing in building structures, concrete experts, public bid advisers). A re-engineering project schedule was laid out to address these problems, which set up a number of steps for IT infrastructure development as well as business process analysis, radical redesign, piloting, and incorporation into the organizational structure.

"Another unfortunate characteristic of most re-engineering attempts has been a consistent failure to deliver the expected outcomes...."

Stage 2: IT infrastructure implementation. Solutions to both problems identified in Stage 1 of the re-engineering attempt were seen by the IT and PR groups as begging a new IT infrastructure based on a local area network (LAN), which was expected to produce immediate gains on its own, as well as support the implementation of changes in the core acquisition

process. In approximately eight months three LAN servers with over 100 networked workstations had been set up. This set the stage for the downsizing of databases and data processing applications from the central mainframe computer to the LAN server.

Stage 3: IT downsizing. The downsizing of database applications from PubliCorp's central mainframe computer to the LAN server was seen by management and employees as having itself increased the efficiency of the core acquisition process targeted for redesign, by allowing fast and decentralized access by all staff involved in the process to product and service supplier information, as well as supporting the implementation of process simplifications aimed at reducing "contact points" between staff.

Although some technical problems and opposition from the old centralized data processing department had to be dealt with, everything seemed to be going as planned and nothing suggested that the re-engineering attempt was not in its way toward a successful completion. The general feeling among management at this stage was that there was only one type of obstacle to be overcome so the re-engineering attempt would eventually succeed: technical obstacles. However, nearly two years had gone by since the initial decision to conduct the re-engineering attempt had been made, and yet no actual changes of radical proportions in any of PubliCorp's core processes had been effected.

Stage 4: Core process re-engineering attempts. After a careful analysis of the process of acquisition of construction services, the PR group developed an initial plan to radically redesign the process. Most of the analysis was based in two main large process models: a workflow model (Soles, 1994; Tagg, 1996) representing the process as a set of over 100 interrelated activities; and a role-activity diagram (Moretti et al., 1996) showing the flow of documents between organizational roles as well as identifying the "contact points" in the process. Figure 1 shows a simplified workflow representation of a small part the process (the one related to selecting a service supplier). Names of activities and organizational roles performing the activities (shown within parentheses) are in the rectangles.

The plan devised by the PR group involved the application of simple re-engineering techniques, such as structuring the organization around outcomes rather than single tasks (Hammer, 1990; Davenport, 1993) and reducing unnecessary controls (Hammer and Champy, 1993; Kock, 1995).

Structuring the organization around outcomes, not tasks, implies having one person perform a set of activities that produce one single output, rather than several people separately performing each single activity (Buzacott, 1996). The application of this principle by the PR group has indeed led to a considerable conceptual reduction in the number of roles, and therefore a decrease in the number of contact points and a consequent reduction in cycle time, in the process shown in Figure 1. However, these reductions were achieved only from a conceptual perspective. In reality, none of the roles in the process could be replaced by any other role, for two main reasons: Different types of expertise were required to perform different activities; and, most important, the whole process was originally designed based on the federal and state laws for

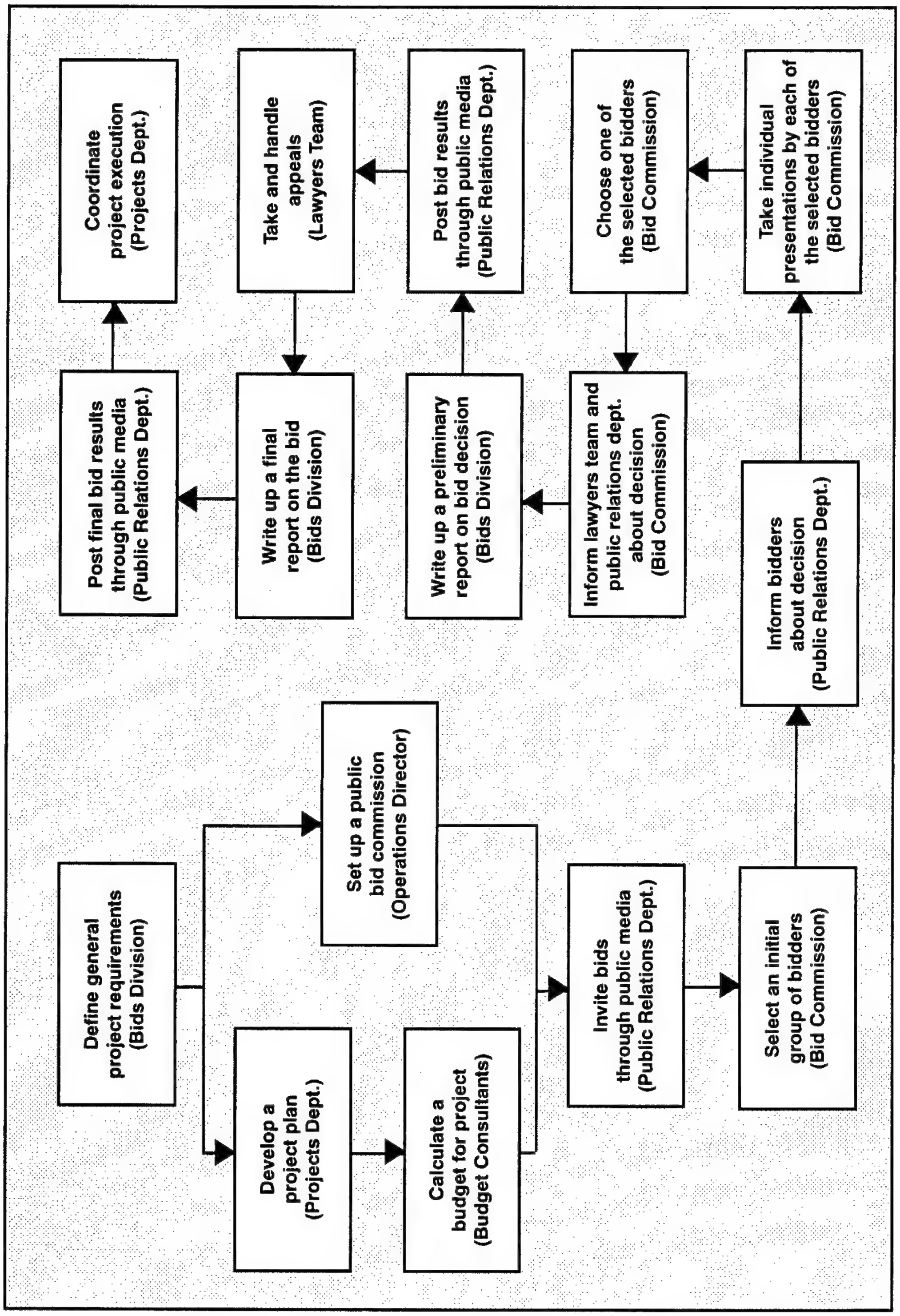

Figure 1: The Process of Selecting a Supplier

public bids, which considerably limited the number of possible changes in its role and workflow structure—even small changes could lead the process to fall outside legal parameters.

For example, some improvements could conceptually have been achieved by pushing the responsibility of calculating budgets from budget consultants to the Projects Department. This could reduce time wasted, as budget consultants typically had to wait for a project plan to be generated and sent to them by the Projects Department before they could start working on a budget for the project (see Figure 1). However, this would likely be achieved at a cost, probably a decrease in the precision of quotes and hence the quality of the overall budget, as the employees in the Projects Department were not prepared to perform the complex calculations involved in generating construction budgets. Moreover, and most important, the law required that an initial budget be produced by an "independent group of recognized experts," hence the assignment of the job to a team of expert budget consultants (all employed by a prestigious consulting firm). The same goes for the taking and handling of appeals on the decision made by the bids commission. For example, could these not be performed by the Bids Division itself? After a careful analysis, the answer was found to be negative, as the law required that a team of attorneys registered with the Brazilian Bar Association be involved in this activity.

"Moreover, and most important, the law required that an initial budget be produced by an "independent group of recognized experts," hence the assignment of the job to a team of expert budget consultants (all employed by a prestigious consulting firm)."

Conceptually, reducing "unnecessary controls" would certainly reduce the time required to select a supplier. A number of these "unnecessary" controls were embedded in the process, even though not all of them are explicitly shown in Figure 1. For example, after a decision had been made by the Bid Commission about the winner of the public bid, it would have to first be communicated to the team of lawyers and the Public Relations Department. The Bids Division would then draft a report on the bid, including the decision made by the Bid Commission, which would then be thoroughly checked by the team of lawyers for full compliance with the complex legal requirements regarding public bids. Finally the report would be checked again by the Public Relations Department, which would then provide a summary of the report to the public through media vehicles—large newspapers and official government publications.

These checks were seen as extremely important to guarantee that no mistakes would be committed that could lead to the invalidation of a public bid on legal grounds. Also, several checks were explicitly prescribed by the law. For example, PubliCorp was required by law to set aside some time to handle administrative appeals through its team of lawyers, an activity that was included by legislators in the public bid process to make sure that its execution could be thoroughly checked and formally questioned by all bidders—and often bids were questioned, typically by those bidders who were unsuccessful in the bid.

Over approximately one year, several attempts were made by the PR group to re-engineer the process of acquisition of construction services and other core processes at PubliCorp. All of these attempts were consistently unsuccessful in that only small process changes were effected, and less than relevant positive bottom-line results (such as possible cost and cycle time reductions) were achieved. The sheer legal rigidity of the process was singled out by a number of PR group members as the main impediment to the success of these attempts. One of these members pointed out that "radical change in public organizations such as [PubliCorp] must be accompanied by radical changes in the law...but changes in the law take time and a lot of lobbying to be achieved...."

Stage 5: Process automation. The problems faced by the PR group led it on a path where eventual destruction was in sight (should it not be able to accomplish at least part of its goals). In the meantime, however, the members of this group had not only become an established and cohesive team at PubliCorp, but also acquired considerable power due to the frequent interactions with PubliCorp's chief executive officer (CEO) and board of directors during its more than three years of existence. In an auto-preservation attempt, the PR group gradually moved away from process re-engineering to automation—that is, the PR group began to simply automate processes rather than trying to radically redesign them. This move took place in an almost imperceptible way, as process automation was presented by the PR group to the CEO and senior executives as process-focused change and therefore analogous to process re-engineering.

The PR group tactics have not gone unquestioned, at least initially, but by then its political power within the organization was enough to eliminate any opposition. For example, some opposition to the PR group was championed by PubliCorp's chief information officer (CIO), who questioned the need for the existence of the PR group since it was not doing its job. The reaction was swift and vicious, leading to the officer's quick dismissal on a few dubious charges of negligence and involuntary accessory to computer theft.

"The sheer legal rigidity of the process was singled out by a number of PR group members as the main impediment to the success of these attempts."

After this incident, the PR group carried on automating processes while the IT group provided the necessary LAN infrastructure support. As a result, four years after the re-engineering attempt was begun, few bottom-line process improvements have been achieved, in spite of the over $8 million spent in the attempt to re-engineer PubliCorp. Nevertheless, at least some in the media thought of the re-engineering attempt as a relatively successful endeavor. Among other distinctions, the CEO was hailed by one local independent newspaper as the architect of a very successful "modernization" of PubliCorp with "state-of-art" IT, and portrayed as a role model for public sector managers.

Structural Factors Preventing Radical Change: A Public Sector View

Arguably, a number of factors could have contributed to the failure of the re-engineering attempt at PubliCorp. It could have been argued that the PR group acted unethically, letting their struggle for power prevent them from searching for genuine radical process improvements in the organization's processes, or that the opposition from employees led to the failure of the re-engineering attempt. It could also have been argued that there was not enough top management support for radical change, as the CEO apparently chose to ignore the warnings of his CIO about the PR group's ineffectiveness, and accept the use of the project by the local media as an example of a successful attempt to modernize a public organization. Finally, it could have been argued that there was not a clear understanding from the part of the CEO or the PR group about what radical process improvement entails, and how it should be properly conducted.

"Process functional heterogeneity can be measured by counting the number of different organizational functions or teams involved in the execution of a process (e.g., CEO, budget consultants, lawyers team)."

However, should all the above circumstances be modified so as to favor re-engineering, there would still be a major obstacle to be overcome at PubliCorp—the process rigidity imposed by the Brazilian government regulation. Other than employees' resistance to change, the case study suggests the existence of a structural resistance to change built in the organizational process. Structural resistance in the core acquisition process targeted for re-engineering at PubliCorp can be seen as the resistance embedded in the process itself, not only due to the way activities were designed to be carried out and by whom, but mainly due to the fact that this design was set out in the form of governmental legislation. PubliCorp's case suggests an avenue for the understanding of process rigidity in the public sector, whereby it can be viewed as a function of at least two process variables—functional heterogeneity and degree of regulation. Table 1 is an attempt to summarize this understanding into a two-by-two matrix.

Process functional heterogeneity can be measured by counting the number of different organizational functions or teams involved in the execution of a process (e.g., CEO, budget consultants, lawyers team). Functional heterogeneity in organizational processes has been found to be highly correlated with the number of knowledge specialization areas found in processes (Kock and McQueen, 1996)—that is, the number of different types of expertise required to perform a process. Due to virtually insurmountable obstacles to a person becoming an expert in several areas at the same time, career choices are made that lead to knowledge specialization. A related consequence is that functional heterogeneity is likely to be high in many processes carried out within knowledge-intensive organizations (Kock et al., 1996).

Table 1 concisely states that a high functional heterogeneity combines with a high degree of process regulation to generate a high structural rigidity in organizational processes. The case study supports this conjecture and provides the

Table 1:
Structural Rigidity as a Function of Functional Heterogeneity and Degree of Regulation

High functional heterogeneity	**Medium rigidity** For example, semi-autonomous public and knowledge-intensive institutions such as state universities. (Re-engineering is likely to fail without changes in legislation.)	**High rigidity** For example, public and knowledge-intensive companies such as inspection firms in knowledge-intensive industries (PublicCorp). (Re-engineering is very likely to fail without changes in legislation.)
Low functional heterogeneity	**Low rigidity** For example, semi-autonomous government inspection branches in non knowledge-intensive areas such as farm inspection departments. (Re-engineering may succeed without changes in legislation.)	**Medium rigidity** For example, government inspection branches in non knowledge-intensive areas such as internal revenue services. (Re-engineering is likely to fail without changes in legislation.)
	Low degree of regulation	**High degree of regulation**

basis for the understanding of the dynamics through which process rigidity opposes attempts to radical process redesign. Demands for high functional heterogeneity lead to a high number of functional roles in processes (e.g., budget consultants and lawyers in PubliCorp's acquisition process), which are then the focal point around which government regulation is created and passed—for example, the legal prescription that construction budgets be prepared by a group of "recognized experts," the budget consultants, and the related criteria prescribed in law to identify and hire these experts.

Government regulation solidifies the procedures involving each one of the organizational functions performing process activities, turning each function into a potential focus of resistance against radical change. PubliCorp's case shows that the line people who carry out knowledge-intensive activities in government-regulated processes are likely to be more familiar with the change constraints imposed by government regulation on those activities than consultants and managers. After all, line workers know their work better than others not directly involved in it (Deming, 1986). Hence, it often becomes their duty to repeatedly inform the members of re-engineering teams (e.g., the PR group at PubliCorp) that radical redesign cannot be achieved the way it is proposed. This may lead to communication breakdowns between line workers and re-engineers as the former group sees the latter group as ineffective, and the latter group sees the former as a biased source of information that does not seem to favor

the re-engineering attempt anyway. The final result is likely to be a failed re-engineering attempt.

What About the Success Stories?

Some of our conclusions may be questioned based on successful examples of process change in the public sector. But an analysis of successful cases reported so far does not invalidate our conclusions, but provides the background on which to frame our understanding of process-related change in the public sector and what it entails. There have been examples of successful outsourcing of core public services or large components of these services to private companies (Coppell, 1994; Mukherjee and Braganza, 1994; Williams, 1994); and of the successful transfer of modified government functions to the community served by local government departments (e.g., police departments) through what are often referred to as "community empowerment" initiatives (Osborne and Gaebler, 1992, Chapter 2).

"There are very few published public sector cases of successful re-engineering in situations of high rigidity, relative to the number of cases about re-engineering in low rigidity (usually fully private) organizations."

Some of the examples above can be seen as instances of successful re-engineering projects by some, as they might indeed have led to radical change in core governmental processes. However, they do not satisfy one basic criterion to be considered in re-engineering projects—that at least one organizational process be radically redesigned, leading to a radical improvement in outcome quality or productivity of the process while it (the process) is still part of the organization. The above examples of successful change in the public sector have relied heavily on the transfer of whole processes or parts of these of these processes to private hands or to the community. After the processes had been farmed out, the stage was set for radical process change. In these cases, however, radical change occurs when the processes are outside the public organization's boundaries. From this perspective, these initiatives resemble much more privatization than re-engineering, as the processes are no longer part of the public organization when they are radically redesigned.

There are very few published public sector cases of successful re-engineering in situations of high rigidity, relative to the number of cases about re-engineering in low rigidity (usually fully private) organizations (although there have been reports of successful "nontraditional" re-engineering in high-rigidity organizations, such as "knowledge-based re-engineering," where part of the expert knowledge involved in carrying out process activities is built in knowledge-based systems; see Nissen, 1997).

Even in situations of medium rigidity, apparently successful cases of radical change in public institutions and companies or government departments resemble more massive downsizing, where the focus is on reducing the size of the organization by shedding off apparently unnecessary departments and personnel, than re-engineering, whose focus is on radically redesigning organizational processes.

Many such examples exist, as the case of the New Zealand Ministry of Agriculture and Fisheries, which downsized thirteen divisions with 6,000 employees in the late 1980s into five divisions with 2,600 employees in the early 1990s (French, 1994), and the case of 13 Swedish government agencies that laid off half of their employees in one blow in 1990 (Naschold and Otter, 1996).

Conclusion and Implications

We have discussed in this paper the role of structural process rigidity as an obstacle to radical process-based change in public sector organizations. A preliminary framework for understanding process rigidity is proposed, where two main influences are identified. The framework proposes that process rigidity is influenced by the functional heterogeneity of processes, and the degree of government regulation imposed on processes in public sector organizations. We argue that high-rigidity processes may not be amenable to radical redesign if they are not outsourced to less regulated organizations such as private companies and community associations. We base our argumentation on the analysis of a failed attempt to re-engineer a service acquisition process in a public sector organization, and on some cases from the literature on public sector transformation.

Two main implications for public sector organizations stem from this research. First, public sector organizations should question whether radical change is really necessary before embarking on large-scale and radical process improvement attempts, as the probability of failure in these attempts is necessarily high. Incremental improvement initiatives have proven to be less risky, while having in many cases yielded highly satisfactory organizational improvements, particularly in process outcome quality (Koehler and Pankowski, 1996; Raff and Beedon, 1994).

Second, public sector organizations where radical change is seen as absolutely necessary can benefit from the analysis of their processes regarding their functional heterogeneity and degree of regulation before initiating their radical change projects. Whenever radical changes in the law are possible in a short period of time (i.e., less than one year), high-rigidity organizations may consider embarking on process re-engineering attempts. However, since radical changes in law usually cannot be quickly accomplished in most democratic countries, most high-rigidity organizations in the public sectors within these countries are likely to be more successful if they move towards other alternative approaches to radical change such as privatization and community empowerment.

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A MULTIMEDIA SYSTEMS APPROACH TO NATIONAL SECURITY POLICY, DECISION MAKING, AND INTELLIGENCE SUPPORT

John P. Crecine and Michael D. Salomone

The amount of raw data available to military and national intelligence professionals is growing exponentially. The revolution in our ability to generate and disseminate data has not led to a corresponding increase in our ability to convert data to useful information. The revolution in information technology, coupled with the natural tendencies in military and intelligence organizations to compartmentalize data (especially when collected using automated or covert methods), combine to hinder military commanders, top-level analysts, and national decision makers from coherently interpreting this profusion of information. The "stove-piping" of data within subunits of an organization makes effective integration at the top much more difficult.

Existing data processing systems make some kinds of information extremely useful, but the systems are incapable of storing, organizing, processing, and retrieving other data types, including text and images, in ways that allow top-level decision makers and analysts to make coherent, comprehensive use of the information. Systems based on new technologies can enable these professionals to more efficiently manage data and information available in electronic forms. The combination of an object-relational database management system with a natural-language processing-based, free-form text search engine, paired with image recognition software and standard structured query language-based search, combined with recent advances in processing, storage, display, and telecommunications technologies, holds great promise for effective information management systems of the future.

Intelligence is information. Raw data from multiple sources and in a variety of forms, brought together in a coherent and timely way, integrated and congealed in the context of particular policy and operational issues or in the

interest of a comprehensive interpretation of particular events, is transformed into useful information. The challenge of managing data available in digital and electronic form, as it is transformed into useful information, is enormous—both in terms of the vast quantities of data and in terms of the incredible diversity and complexity of the raw data elements routinely collected. The fundamental problem is that a huge, eclectic, and rich array of data must be organized and stored in such a way as to allow for retrieval in targeted and often unanticipated ways for unanticipated purposes.

The net effect of modern information and communications technologies has been to exacerbate rather than alleviate the information management problem for all professionals, not just those in the military and intelligence communities. Compartmentalization and division of labor, the hallmark of organization and bureaucracy, creates dedicated, specialized, and separate information management and data processing systems. This "stove-piping" effect means that different data types and data collection organizations have a tendency to operate as closed systems, up through several organizational levels. Once data has been processed through several organizational levels, the initial data elements or observations or transactions are "lost" or unavailable to top-level analysts or decision makers. Whether the initial data element is a paragraph in a trade journal or an internal government memo, or is a portion of the yield from a satellite's remote sensor, a readiness report for a low-level military unit, or a simple accounting transaction, the raw data is seldom easily accessible to top-level analysts or decision makers, and it is almost always impossible to combine

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data from different sources ("stovepipes") to suit unanticipated needs. Modern information technology generally accentuates and multiplies the stove-piping problem.

As we move into the next century with an accelerating pace of technological change, an important question is whether modern information and communications technologies can be used to alleviate a problem they have helped create. Can technology aid in the targeted retrieval and purposeful synthesis of the technology-driven explosion in the quantity and diversity of raw data in analog and digital formats? Just as it took an important enabling technology—HTML (HyperText Markup Language), Web browsers (Mosaic/Netscape), and search engines (Lycos, Excite, AltaVista, Yahoo)—to make the Internet useful for tens of millions of users with eclectic interests, military, intelligence and other professionals need enabling technologies to make the rapidly growing mountains of increasingly diverse data types professionally purposeful.

In the language of the national security and intelligence community, "Can modern information technology rescue the intelligence fusion process from the enormous information overload, storage, retrieval, and synthesis problem?"

The Nature of the Data and Information Management Problem

This challenge is complicated, since data relevant to a particular issue is collected from a very wide array of sources, usually by different people in different organizations, and often for narrower purposes than those of relevance to national intelligence organizations, policy makers, or a military commander. The efficient and cost-effective management of potentially relevant data and information is a central issue for all organizations, and particularly so for the top-level decision making, policy, and intelligence functions in military organizations and the national intelligence community. Data and information relevant to these functions is incredibly diverse, compiled in great quantities, in widely varying formats, and from wide-ranging and shifting numbers of sources.

"The efficient and cost-effective management of potentially relevant data and information is a central issue for all organizations..."

Much of the data waiting to be collated and synthesized into information are memos, journal articles, news accounts from the print media, reprints, translations, notes, papers, and transcripts—free-form text. Still other data take the form of photo images, sensor outputs, signals, video images, tabular alpha-numeric data, maps, news accounts from the electronic media, or audio clips. Data and information resources are generally dispersed geographically and organizationally. The management of information for top-level decision making, policy, and intelligence functions is a formidable task and, as currently conducted, is necessarily very labor intensive.

Consider only the accelerating information management sub-task of battlefield management. As new sensors and intelligence gathering devices are created to support development of dominant battle space awareness, there is a corresponding and geometric increase in the amount of information the commander and the supporting intelligence organizations must

comprehend, at least in theory. Effective commanders must be increasingly selective in the information to which they attend, or they need to capture the benefits of automation in executing the information management portion of their command function.

Consider the real-time intelligence analysts' task of interpreting rapidly changing events, with a pile of articles, notes, demographic charts, biographical sheets, maps, books, Cable News Network (CNN) video tapes, and newspaper clippings on his or her desk. First, is this eclectic pile of data the right pile for this event? Second, can the analyst quickly sort through, analyze, cross-reference, and correlate information in support of a competent situational analysis? Under the best of circumstances, this a daunting information storage, retrieval, and organizational task.

"In a bureaucratic setting—be it a military or intelligence organization—information seldom is delivered to a commander or analyst without an associated context, framework, or interpretive suggestion."

The problems faced by the commander in a battlefield situation or by an intelligence analyst are surprisingly similar. Due to the pressures of time or the overwhelming amounts of potentially relevant information, there is an information overload problem of considerable proportions. Whether individuals are seeking the "right answer," an accurate situational analysis, an adequate understanding of events, or a framework for understanding the phenomena or event of interest, individuals must be selective, focused, and guided by some sort of paradigm or crude framework in interpreting the data they have. For the most part, history and experience, shaped by training, dominant scenarios, and "lessons learned" from roughly similar situations, help individuals sort through the infinite combinations and permutations of potentially relevant information.[1]

In a bureaucratic setting—be it a military or intelligence organization—information seldom is delivered to a commander or analyst without an associated context, framework, or interpretive suggestion. Often organizational subunits are formed around a particular paradigm or belief system and information coming from such organizational units comes laden with those biases and selectivity filters. Organizational preprocessing is hardly unexpected. The various elements of the technology-driven information revolution combine to deliver vastly greater quantities of information in vastly more diverse formats (data types), resulting in a geometric growth in the potential information processing and synthesis problem. This problem is made manageable in current settings by even greater reliance on dominant paradigms generated by personal histories and training and by even greater selectivity and filtering by bureaucratic information providers. The information revolution has been, in fact, a revolution in data generation and dissemination, not in data understanding.

The information revolution does not naturally create a greater ability of chief

[1] This is illustrated in Graham T. Allison's classic *Essence of Decision,* (Little Brown, 1969) in analyzing the Cuban Missile Crisis using three theoretical approaches or points of view.

executive officers, commanders, and analysts to "get it right." Here we'll discuss some of the technical reasons why the revolution in our ability to generate and disseminate data has not led to a corresponding increase in our ability to convert data to useful information. We'll describe some technical developments that we believe can help improve the data-understanding-to-useful-information conversion process, through a partial automation of the new, more diverse, and difficult information management task.

The explosion in the volume and diversity of intelligence information is occurring in an environment of declining financial resources for intelligence assessment, military decision making, and national security policy making. Professionals in these areas must achieve dramatic increases in the efficiency and effectiveness of their information management and fusion systems, merely to maintain current levels of effectiveness of intelligence, decision making, and policy functions.

Applying Recent Advances in Technology to the Challenge

How might one bring modern information processing technology to bear on national intelligence tasks? Recent advances in many areas foster the hope of creating affordable, comprehensive information systems. Among these are:

- multimedia-data applications,
- analog-to-digital conversions and data compression,
- artificial intelligence applications in image recognition and natural language processing,
- modern telecommunications, including both wide-area and local-area network technologies,
- client/server computing systems,
- distributed database systems,
- visualization and display technologies,
- digital storage media, and
- computing technologies.

Systems based on new technologies can enable government and military personnel to more efficiently manage the exponential growth rate of data and information available in electronic forms, and to more effectively deal with the challenges presented by the proliferation of data formats. A comprehensive and affordable approach to the intelligence information management task is now possible due to advances on several technical fronts.

"Major advances have occurred recently in the ability to store, access, and process vast amounts of raw data in a variety of forms, and to do so using digital data formats."

Major advances have occurred recently in the ability to store, access, and process vast amounts of raw data in a variety of forms, and to do so using digital data formats. First, recent advances in optical and magnetic technologies make the storage and retrieval of terabytes (a

million megabytes) of digital information possible and affordable. A "jukebox" of high-capacity, read-write compact disks now costs less than $5,000 and stores a terabyte of information. These new jukeboxes can replace a $2 million to $3 million system that was state of the art only one or two years ago. And the new, digital video disks (with an order of magnitude greater capacity) are not far behind. In order to grasp the magnitude of this available storage capacity, a terabyte represents more text than is stored in most university libraries.

"...it is the advance in information storage and retrieval strategies (database management systems, or DBMSs) that makes it possible for professionals to facilitate the appropriate collection of needles in an expanding set of exponentially growing, data haystacks."

Second, rapid advances in video compression technologies, driven by the broadcast entertainment industry, have resulted in the electronic storage and retrieval of complex, high-resolution digital images, full-motion high definition televison (HDTV), and animations and simulations. Data compression and expansion involves conversion to a digital format, which increases the accuracy and reliability of communication transmissions and provides for a greater ability to manipulate sensor and image data.

Third, the super computers of a couple of years ago are now the reduced instruction set computing (RISC) chips in personal, desktop computers, at 2–5 percent of the cost. Processing power for digital data formats is available, increasingly powerful, and inexpensive. Parallel processing PCs are now readily available for $5,000 to $10,000 (usually configured for image processing and multimedia production tasks).

Finally, the information superhighway, fiber optic cabling systems, digital direct broadcasts, cable, and satellite systems coupled with advances in client/server architectures all mean that the collection and storage of information can be geographically and organizationally distributed, without paying the usual penalties (e.g., lack of access or incompatibilities).

The rate of change in technology is so rapid, the efficiencies to be gained so great, and the cost savings so massive, that to use anything other than commercial, off-the-shelf (COTS) hardware and software would be foolhardy. An acquisition process that fails to closely track the massive, rapid, and revolutionary advances of the commercial sectors of modern information technology is fatally flawed.

For these advances, largely in hardware and microelectronics, to lead to real advances in the information management side of military and intelligence functions, there must be corresponding advances on the information processing or software portions of the information management system.

Enabling Technologies: Database Management and the Problems of Free-Form Text and Images

Although advances in hardware, storage, networking, and display technologies make many storage and retrieval tasks economically and technically feasible, it is the advance in information storage and

retrieval strategies (database management systems, or DBMSs) that makes it possible for professionals to facilitate the appropriate collection of needles in an expanding set of exponentially growing, data haystacks. Data are generally in locations remote from users. Different databases assembled, owned, and maintained by different agencies and sources can be distributed over a secure network. Distributed databases can be comprehensively searched and information in multiple forms can be selectively retrieved and brought to bear on questions of particular interest to analysts or policy makers in a timely fashion.

Requirements for Access to Useful Information: Database System and Search Engine

Two new areas of progress combine to make possible a broad, general purpose national security and intelligence information management system. One area consists of a new approach to database management: a data storage and organization strategy. For example, existing relational database management systems (RDBMSs) allow the user to identify books in a database, based on a Library of Congress code or index. A new, object-oriented database management system (ODBMS) allows a user to examine not only the Library of Congress code, but all of the text in all the books in the database and go straight to the relevant passage or paragraph.

The second area relates to "search engines" for free-form text and images, a data search and retrieval strategy. This consists of, first, a natural language processing "search engine," where concepts and abstract representations of content, as well as key words, are used to search and identify relevant information (the needles) among the wide array of data types (the haystacks), and in a far more precise manner than has ever been possible. Second, it includes image recognition software that allows one to search digital images (still or video) based on color, composition, objects, structure, or other characteristics to identify particular records that correspond to search criteria or user-provided examples.

"For more than 25 years, relational databases have formed the basis for most of the automation of administrative and financial information systems."

Relational Database Management Systems and Their Limitations

For more than 25 years, relational databases have formed the basis for most of the automation of administrative and financial information systems. Relational databases allow multiple users to systematically search a range of different, fixed-record-length files. Fixed record length means relational databases work very well for numbers and alphanumeric data of fixed length (e.g., a 35-character record containing formal names). In the search and retrieval process, the RDBMS can examine individual records using a standard query format (SQL, or structured query language, the industry standard), and pick out those records that meet the criteria.

When data is located in complex multimedia formats (e.g., a journal or news article or free-form text, a video, an image, a computer-aided design [CAD] drawing, or an audio recording), traditional relational databases store data elements as uninterpretable BLOBs (Binary Large Objects). Customarily, relational database users will develop a coding scheme or "tag" for each type of BLOB. The data or content in any particular type of BLOB is accessible only through the coding scheme. For example, the text and content of a library book is stored as a BLOB in a RDBMS, and the BLOB is accessed through the Library of Congress code or index. The establishment of a fixed coding scheme, in effect, implies that all future uses for the content of a BLOB data type are known and have been embedded in the code. In the book-in-a-library example, the implication is that the Library of Congress code for the book captures all of the relevant content of the book. This assumption is seldom appropriate for the needs of top-level analysts, decision makers, and policy makers, and is almost certainly inappropriate for any knowledge domain that is rapidly changing. Coding schemes in a RDBMS are difficult to extend, once established.

"Moreover, and most important, the law required that an initial budget be produced by an "independent group of recognized experts," hence the assignment of the job to a team of expert budget consultants (all employed by a prestigious consulting firm)."

In response to the development of object-oriented programming and database technologies, most leading RDBMS suppliers have added what they term as an "object layer" to their RDBMS. The object layer generally refers to a coding scheme used to provide access to data stored as BLOBs.

Object-oriented Database Management Systems: Overcoming RDBMS Limitations

In terms of data complexity, relational databases only allow for the efficient storage and retrieval of fixed-record-length, alphanumeric data. The proliferation of rich, and more complex digital data types (non-fixed length records, containing data other than alphanumeric) led to the development in the early 1980s of object-oriented DBMSs (ODBMSs). While allowing for more complex data types, and being entirely extensible with respect to data types, ODBMSs do not have an effective method for querying the data—there is no SQL equivalent.

However, there are many additional benefits of ODBMS that have to do with systems development issues, which use the inheritance and encapsulation nature of "objects" in object-oriented programs. The elements of object-oriented database management systems represent very efficient building blocks for other applications.

Inefficient Method of Combining the Advantages of RDBMS and ODBMS

Most relational database management systems have attempted to capture the benefits of object-oriented database

management systems by placing an object layer on their existing systems. Although such an approach preserves legacy applications (SQL-based), it possesses significant flaws. Grafting a fundamentally different system to an old architecture means that the basic search engine is unable to understand how to optimize storage and retrieval features of object data records. At best such an approach will be extremely inefficient: slow, and requiring extra processing, storage, and communications resources. The magnitude of the inefficiency problem is geometrically proportional to data complexity and the size of the database(s).

Object-Relational Database Management System

A more straightforward and promising approach is to re-architect a DBMS from the ground up, using the following methods:

- Incorporate artificial intelligence software with a knowledge of objects.
- Create "smart objects."
- Construct query languages (including SQL legacy systems as a subset).
- Redevelop client/server architectures.
- Integrate extendibility of data types into the re-architectured system from the beginning.

Such an object-relational database management system (ORDBMS) was created in the early 1990s and has been operationally tested in a wide variety of applications, with extremely diverse sets of data types. The ORDBMS approach is ideally suited to the size, complexity, extendibility requirements, and the need for flexible (and inherently unpredictable) search strategies that characterize national intelligence database applications.

Search Engines

Finally, a key to a superior solution to the management of intelligence information is the ability to precisely identify individual records (data objects) of extremely varied types, and to collate them from a widely distributed set of heterogeneous sources. Natural language has evolved over many millennia as a way to describe, with precision, diverse kinds of objects, information, and abstractions. Natural language is adapted to the interpretation, perception, and correlation tasks of natural intelligence. A natural language processing search engine is a manageable approach to finding the needles in the diverse, large, and expanding haystacks of potentially relevant information.

"...a key to a superior solution to the management of intelligence information is the ability to precisely identify individual records (data objects) of extremely varied types, and to collate them from a widely distributed set of heterogeneous sources."

Pure keyword indices, whether weighted or not, can provide a useful first cut in identifying and retrieving user-defined, relevant intelligence information. However, the failure to "understand" the

content of individual data records with no more depth than a simple frequency of keyword mentions in a data record highlights two problems. First, too many "relevant" records will be identified. Second, if a particular concept or substantive element of content is described in different words in several different sources or records, many relevant records will be missed. The proposed natural language search engine has the ability to represent a particular unit of text or language as an abstraction of data that contains concepts and information, in addition to including a more sophisticated method for counting keywords within that unit of text.

"In most information storage and retrieval systems...for performance purposes, search and retrieval is a two-stage process."

General Indexing and Search, and Storage and Retrieval Strategies

Indexing and Search Engines

In most information storage and retrieval systems, including several popular Internet browsers (retrieval systems for Web pages), for performance purposes, search and retrieval is a two-stage process. First, all relevant records and data elements in storage are "read and analyzed" by an application or routine that could be viewed as a general purpose search engine. The routine analyzes each record or file and notices key features of that file, using those features to create an index for that file or record. For free-form text, the index might consist of key words, perhaps weighted by their frequency or relative location in the text. In more sophisticated natural language processing routines, "concepts" (key words, linked together in a particular linguistic structure), and weights attached to the relative importance of key words and concepts in the text might also be included.[2]

The second stage is to retrieve a targeted subset of the records represented by the master index. To do this, the routines analyze a query by the same routines in the same way that individual records were processed in creating the master index, and a special, much smaller index is created for the query. The index for the query is then compared with the master index. The result is a detailed report of pointers to that subset of individual records where there are matches between the query's index and the master index. Armed with this report, the user retrieves those records that look particularly interesting. The initial indexing of individual data records and files, and the search for and identification of individual records is a very similar process.

In an image understanding routine, visual content—the structure, composition, texture, color, or object—along with ancillary information (e.g., the source or date) might form the basis for the image's index. A master index could then be constructed that would be an overlapping set or a composite of all the individual indexes for individual records. Nearly all existing

[2] The leading knowledge-based, natural language processing system comes from the Center for Machine Translation at Carnegie Mellon University (Jaime Carbonell, founding director). A simpler version of the core of their machine translation system is the basis of the Lycos™ Web browser.

image and video search and retrieval systems rely entirely on narrative, linguistic descriptions to identify a set of images or video sequences that are then examined visually by the user.

Use of Linguistic Content to Identify Images

Indexing and retrieval of video sequences or "clips" from vast stores of video data, based on content, implies that the content of the video clip is used, directly or indirectly, as the basis for storage and retrieval. In order to capture as much content as possible, the linguistic content of the audio track is treated as part of the video clip's content, and in many cases, for storage and retrieval purposes the audio track content is assumed to capture all of the video clip's content.

A leading technology in this regard is embodied in the Carnegie Mellon University Informedia Project. Speech recognition software, Sphinx II, is used to automatically translate a video clip's audio track into free-form text.

Language processing software similar to that used in Lycos™ (http://www.lycos.com/), a popular Internet Web page search engine, generates a content-based index for the video clip. It is this index that forms the basis for search and retrieval of video clips. It should be noted that approaches that depend exclusively on natural language understanding generally fail to sufficiently categorize the associated imagery.

Indexes and searches in the approach advocated here involve both natural language processing and image recognition software, functioning both as indexes and search engine.

Composite Search Engines

Search engines designed for use with a single data type (e.g., text, image, video clip, or sensor output) may be useful in delimiting human search of more complex or ambiguous data and content. The question remains as to whether one can make several search engines (one for each data type) work in tandem to produce results superior to one search engine working alone (Jennings, 1994). We anticipate that the answer is "yes." An important step in creating the type of flexible information management system advocated here for national security and intelligence use is to create a superior, composite search engine from several "single data type" search and retrieval systems. A composite search engine would, at minimum, include both natural language understanding-based and image understanding-based search engines.

"Search engines designed for use with a single data type... may be useful in delimiting human search of more complex or ambiguous data and content."

Two issues, both heavily influenced by the context and knowledge domain of the search, must be addressed as this composite search tool is developed. First is the role of ancillary information and data in identifying appropriate records. (For example, a military analyst might profitably use historical time lines, place names, person name files, and newspaper articles to correctly locate video clips with particular content.) Second is the purpose of the search, which will help determine relative weights placed on the dimensions of the

search. Both issues influence the choice of the archive of video, text, and other information to test various components of any composite search engine.

Common Approaches to Storage and Retrieval of Video Sequences

The approach taken by the Carnegie Mellon Informedia™ project (mentioned above) to storing and retrieving video material, although considerably more sophisticated,[3] is similar in broad outlines to that employed by large broadcast news organizations. Both make use of linguistic content descriptions for indexing or cataloging video sequences and digital images and for retrieving them.

CNN has developed a system for storing, cataloging, and sometimes retrieving the hundreds of thousands of hours of raw video feeds (eight feeds, more or less continuously, over each 24-hour period) and the 5 percent that make broadcasts.[4] CNN has a human viewer who, as the video feeds are received from the field, divides them into sequences or "clips" with a beginning and end, and types brief notes describing their contents. It is the notes that are searched (not the images themselves), via computer, pointing to a place on a particular video tape, which has been catalogued, much like a book, and placed on shelves.

"None of the language or image processing components that make up the composite information retrieval and search engine will be 100 percent accurate."

That this imagery and its associated linguistic descriptions or narratives/transcripts have only somewhat overlapping content is demonstrated by the fact that more than 80 percent of the requests for historical footage or video clips made to the CNN Library are simply for images or particular kinds of visual scenes and settings. Particular requests for historical video clips generally have little or nothing to do with story content. What is requested is a visual backdrop to an often unrelated story. This approach is insufficient for intelligent analysts and national security policy makers.

Performance Characteristics of Composite Search Engines

None of the language or image processing components that make up the composite information retrieval and search engine will be 100 percent accurate. An important question (once the "best of breed" search engine components are identified) is to how reliably each component has to perform in order to be good enough. Because each component is embedded in a complex system and interacts with a particular knowledge domain, there is no easy answer. And the best systems will exploit the characteristics of particular knowledge domains.

[3] This strategy uses audio track and speech recognition software to generate an automatic transcript that presumes to describe content of the video.

[4] This description results from extensive discussions with Cable News Network, particularly with the News Tape Librarian.

For example, the best available speech recognition software today may be 85 percent accurate in speaker-independent settings with a 20,000 word vocabulary, and 98 percent accurate with an 80,000 word vocabulary, but the larger vocabulary system may cost 16 times as much and take 10 times as long to search. Video sequences indexed using the audio sound track and 85 percent speech recognition may be "good enough"—accurately indexed and retrieved under such conditions with an elaborate, detailed query, which depends on the uniqueness of the clip or query and the redundancy of the responses to it. Or, when coupled with image recognition software that is 75 percent accurate on identifying video clips, the combination of search tools may be such that the accuracy of the composite system is substantially better than the accuracy of either component. Or the opposite may be true, depending upon the content and the characteristics of the knowledge domain. Information on troop movements and real time deployment is different from information about national political subgroups, which is different from water resource information or the characteristics of a nation's secondary educational systems.

One Approach to Information Management for Intelligence Analysts

The combination of an ORDBMS with a natural-language-processing-based, free-form text search engine paired with image recognition software and standard SQL-based search, when coupled with recent advances in processing, storage, display, and telecommunications technologies, holds great promise for the information management systems appropriate for military and national intelligence functions.[5]

Multimedia Archival Systems, Inc., (MmAS) is developing a robust information management system[6] to accommodate the automatic indexing, archiving and retrieval needs of intelligence analysts and national security policy makers and decision makers with diverse data needs that remain underserved by current technological approaches. Integrating key portions of standard Web browser technology (Netscape Navigator™ and Microsoft Internet Explorer™) with the capabilities of the Informix/Illustra™ ORDBMS, Multimedia Archival Systems has developed a prototype of a client/server system for indexing, cross-referencing, and retrieving data stored in free-form text, audio, and video image formats, along with standard RDBMS data types, to support specific national security decision making,

"The prototype design (of the information management system) employs speech recognition, natural language processing, and image recognition technologies."

[5] The overall system described has a patent pending and uses existing and pending commercial licenses from Netscape™, Illustra™ Information Technologies/Informix, SUN Microsystems™, and Carnegie Mellon University, issued to Virtual University International, Inc., with sublicenses to MmAS.

[6] MmAS shares in the technological developments of Virtual University International, Inc., which is using similar technologies in its university course content preparation and delivery system.

intelligence assessment, and military command function needs. The prototype design employs speech recognition, natural language processing, and image recognition technologies. Future versions will allow users to create automatic cross-referencing of data records of different types. The proprietary automatic cross-referencing scheme is a kind of correlation coefficient or measure of association for eclectic, nonalphanumeric data and aids in the synthetic, intellectual tasks common to most top-level national security and intelligence policy makers and analysts.

"A standard build-to-specifications at a fixed price approach will almost certainly fail to exploit the latest technology."

Object-oriented programming techniques create extensible systems, both in terms of data types and applications. The Multimedia Archival, Inc., information management system uses COTS technologies and industry standards, and it has the common look and feel of the leading Internet browsers.

The Internet protocols and design standards form the primary client/server architecture and distribution system and it, rather than the computer operating system, functions as the software development platform for the systems outlined here. An "Internet-compliant" strategy tracks the Internet's rapidly evolving technological advances and, in so doing, maximizes markets and maintains compatibility with the widest array of COTS hardware, communications, software, and information resources. This approach is also referred to as an Intranet system or strategy.

In the context of national security and military intelligence applications, the system described here has two major functions. First is to customize the MmAS client/server information management system to the particular demands of intelligence and national security data. This means creating efficient natural-language and image-recognition-based search engines, user interfaces, and data objects customized for the particular data types used in national security and intelligence systems. The second is to organize data capture operations that will convert raw and analog data—text, images, sensor information—into digital form, which then can be stored and retrieved efficiently using ORDBMS server technology licensed from Informix/Illustra™ (through MmAS).

Implications for the Acquisition Process

If government national security and intelligence organizations are to capture the functional and economic benefits of the rapid revolution in information technology, it must use COTS hardware and software to the greatest extent possible, must use industry standards whenever possible, and must anticipate and follow trends in technology. The task outlined in this paper is a complex systems integration task perhaps best performed by a nongovernmental unit operating under a general, task-defined contract and free to acquire necessary COTS hardware and software, integrating components to meet the general needs of the client. A standard build-to-specifications at a fixed price approach will almost certainly fail to exploit the latest technology.

Commercial Applications of the Underlying Technologies

Internet-compliant MmAS information management systems have applications in any situation in which the core information for an enterprise or profession does not fit the fixed-record-length, alphanumeric-data requirements of the standard RDBMS model. Commercialization opportunities for the information management system broadly outlined here have been investigated for use in national intelligence, print and broadcast news media, as the course content preparation and delivery system for virtual universities, and for use by health care providers (Electronic Clinical Patient Records/ Telemedicine). Current development activity is aimed at the education, distance learning, and corporate training markets.

Conclusion

Modern information and communications technologies, while offering tantalizing possibilities to military and intelligence professionals, have certainly made their jobs more difficult and complex. The stove-piping problem inherent in national security and national intelligence organizations is exacerbated by current information and database technologies. Whether a decision maker or analyst is trying to understand context, identify missing pieces of information, or make bets on future scenarios; whether attending to specific real-time needs of a military commander or attempting to identify clear trends and major long-term tendencies of a national system; whether using the methods of a Maigret or a Sherlock Holmes, he or she could use a "technical fix" that helps put together the pieces of diverse, rich information together into a coherent whole.

Can modern information technology help? Recent technological developments, particularly in the software arena, hold considerable promise for enabling national security and intelligence professionals to better cope with the information retrieval and synthesis tasks necessary to perform well in what is often an "overly rich" information environment. The answer is maybe—but not if the sole concern is modifying legacy, relational database systems.

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IDENTIFYING FACTORS THAT CONTRIBUTE TO PROGRAM SUCCESS

Maj. Kenneth J. Delano, USAF

Department of Defense acquisition programs and projects frequently experience cost overruns, performance deficiencies, schedule delays, or cancellation. Often, a good program manager using proven program management practices can mean the difference between success and failure. By surveying program managers, examining successful programs within DoD and relevant literature on program management and defense acquisition, we have identified factors that contribute to program success.

Department of Defense (DoD) acquisition programs and projects frequently experience cost overruns, performance deficiencies, schedule delays, or cancellation. U.S. defense acquisition is arguably the largest "business" in the world. Annual purchases by DoD of approximately $178 billion exceed the combined purchases of General Motors, Exxon, and IBM. Defense acquisition involves almost 15 million contract actions annually and employs more than 165,000 civilian and military workers who manage research and development, procurement, logistics, and support activities (Sammet and Green, 1990).

With such a large system, errors and inefficiencies are bound to occur. Examples are frequently reported in newspapers and magazines, which use these examples to illustrate the poor state of the DoD acquisition system. The real impact (beyond the negative publicity) is on defense readiness, performance, and cost effectiveness. Since World War II, six blue-ribbon commissions have studied DoD acquisition and recommended remedies. Adoption of some of these recommendations, new regulations, and laws has failed to alter the paradigm ("Rx for Ailing Procurement System," 1990).

This study sought to identify factors that contribute to program success. The factors identified can effectively improve the current acquisition system, vice the multiple attempts to reform the system itself.

We used two techniques to determine these factors. First was a survey in which program managers were asked to identify factors they believed were key to their programs' success. We also conducted a "factor analysis" of acquisition literature.

Approach and Methods

The approach used is based on work by Emory and Cooper (1991), and can be summarized thus:

- Define the management question. (In this case it is "What are the most significant factors contributing to successful DoD acquisition programs?")
- Identify research population and sample to be questioned.
- Develop questionnaire surveys.
- Collect data.
- Analyze data collected.
- Determine factors that contribute to program success.

Population, Questionnaire, Data Collection

Thirty-two program managers participated in the survey, the text of which is in Appendix A. Survey responses were unsigned and untraceable as to the respondent. Each respondent was provided with a blank copy of the survey and a self-addressed stamped envelope.

The questions were developed to help the respondents identify what they felt were key factors of program success. Areas addressed include program management, personnel, resources, and user requirements. These factors were used in a literature analysis to identify those that contribute the most to program success.

The survey results were analyzed to select key factors considered important by the respondents. These factors were ranked in order of importance and categorized into common subject areas.

With data from the survey results, we applied McFarland's (1992) factor analysis technique. This technique measures the occurrence of key factors in a review of relevant literature. The occurrence of a key factor in each article is noted. In a representative sample of literature, one can determine the relative importance of each key factor to the subject by noting and comparing the number of occurrences. We ranked those occurrences in order of frequency and by subject area.

With these results in hand, we compiled a list of factors that contribute to program success. Those mentioned most frequently (as determined by factor analysis) were the ones examined for identification as factors of success. Qualitative indicators such as the degree of applicability and history of success of each factor were considered.

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RESULTS

SURVEY RESULTS AND ANALYSIS

Eighteen surveys were returned—a 56 percent rate of return. This response rate is judged sufficient to validate the survey results. (One program manager cautioned against expecting a high response. "We are all surveyed out," he said, explaining that program managers are frequent targets of official and unofficial surveys.)

The responses to the first survey question "Please rank the following in order of their importance as indicators of program success: meets initial operational capability date, meets technical performance objectives, meets logistics supportability objectives, works well when fielded, meets cost objectives," are presented in Table 1.

Two factors, technical performance and actual performance (works well when fielded) were deemed most important. By averaging the ranking from all responses, technical performance was first. Judged least important were meeting logistics supportability objectives and meeting cost objectives.

Answers to the second survey question ("List the factors you believe contribute to the success of a program or are indicative of program success") fell into eight categories:

- total team concept;
- program manager skills;
- program manager responsibility and authority;
- well-defined requirements;
- stability;
- quality people;
- adequate staffing; and
- acquisition strategy.

Program managers were next asked whether they were helped or hindered by the user, support agencies, higher commands, Congress, and the General Accounting Office (GAO). They responded that user involvement and input helped their program, and that for the most part,

Table 1. Survey Results

Rank of Program Success Indicators			
Most Important	**Least Important**	**Average Rank***	**Program Success Indicator**
12.5%	31.3%	3.1 (3)	Meets Initial Operational Capability Date
37.5%	6.2%	2.2 (1)	Meets Technical Performance Objectives
0%	31.3%	4.2 (5)	Meets Logistics Supportability Objectives
37.5%	18.7%	2.4 (2)	Works Well When Fielded
12.5%	12.5%	3.1 (4)	Meets Cost Objectives
*(1 = highest)			

they viewed involvement from support agencies and higher commands as a hindrance. All those who responded felt that involvement of Congress and the GAO in specific programs was a detriment to program success. Table 2 presents their responses.

Finally, program managers were asked to rank a list of program success factors identified from a preliminary literature review using a Likert scale (1, not very important; 2, somewhat important; 3, important; 4, very important; 5, critical). The factors and results are presented in Table 3.

The respondents felt that program manager communication and leadership skills were important. They also felt that the type and quality of people assigned to support the program was important, as was a good relationship with the user organization. Adequate resources and stability (requirement, design, and funding) were judged to be next in level of importance. They did not believe that the degree of technical difficulty (low or high) of the program affected program success. The results also indicated that the program manager's technical ability or use of a total quality management program were not considered to be very important to program success.

Literature Factor Analysis

The factor analysis technique (MacFarland, 1992) measures the occurrence of key factors in a survey of literature. The occurrence of a key factor in each article is noted. In a representative literature sample, the relative importance of each key factor to the subject area can be inferred.

By comparing the occurrences of a key factor in a number of articles against occurrences of other key factors in the same articles, one can calculate the relative importance of each factor . For example, if a key factor is mentioned in 5 out of 10 articles, it has an importance of 50 percent for comparison purposes. This figure can be compared to those calculated for other factors and conclusions drawn as to the importance or emphasis the literature places on each factor.

The results from the first, second, and fourth survey questions were used in developing factors used in the literature review. The factors were divided into two main areas: acquisition factors and

Table 2. Survey Results

Has Program Success Been Helped or Hindered?		
Factor	**Helped**	**Hindered**
User	71%	29%
Support Agencies	20%	80%
Higher Commands	20%	80%
Congress	0%	100%
General Accounting Office	0%	100%

Table 3. Survey Results

Program Success Factors Rank By Importance	
Average Score	**Program success factor**
4.42	Program manager's ability to communicate
4.25	Type and quality of people associated with program
4.25	Program manager's ability to lead
4.25	Good relationship with the user organization
4.17	Resources: People, facilities, money
4.08	Product requirements and design stability
3.91	Funding stability
3.83	Good relationship with the prime contractor
3.58	Program's acquisition strategy
3.58	Program manager's acquisition experience
3.25	Program personnel continuity
3.00	Program manager continuity
3.00	High degree of technical difficulty
2.92	Program manager's field experience
2.67	Program manager's technical ability
2.33	Total quality management program
2.25	Low degree of technical difficulty
1 = Not very important 2 = Somewhat important 3 = Important 4 = Very important 5 = Critical	

resource factors. Tables 4 and 5 give the results of the literature survey, with each source denoted by a letter. Table 6 lists the correspondence to the actual source in the bibliography.

The literature factor analysis reveals that there is a broad range of subject matter within the general topic of acquisition and program management. The highest correlation between a factor and the literature reviewed was 47 percent. A tie occurred between three factors: quality people, well-defined requirements, and acquisition strategy. All had a correlation of 47 percent. This reflects the fact that literature articles frequently focus on these

Table 4. Acquisition Factor Analysis

Factor	Source																			Total	Percentage
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S		
Well defined requirements	X		X	X	X		X	X			X		X	X						9	47%
Acquisition strategy	X	X		X	X			X	X		X					X		X		9	47%
Works well when fielded	X							X	X		X					X		X		6	32%
Stability	X		X	X	X			X								X				6	32%
Good relationship with contractor	X				X		X								X					4	21%
Total quality management program								X									X		X	3	16%
Meets performance objectives	X			X																2	11%
Meets cost objectives				X																1	5%
Meets initial operational capability date																				0	0%

Table 5. Resource Factor Analysis

Factor	Source																			Total	Percentage
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S		
Quality people	X		X	X	X			X					X	X	X			X		9	47%
Program manager responsibility and authority	X		X	X	X		X					X		X		X				8	42%
Total team concept	X				X		X				X	X		X	X					7	37%
Program manager skills	X			X	X			X				X	X	X						7	37%
Congressional involvement				X	X									X						3	16%
User involvement							X					X								2	10%
Adequate resources			X					X												2	10%
Adequate staffing															X					1	5%
Support agency involvement							X													1	5%
Higher command involvement							X													1	5%
Program manager's technical ability	X																			1	5%
General Accounting Office involvement																				0	0%

Table 6. Correspondence Between Codes and Sources

A:	Baumgartner, Brown and Kelley
B:	Beltramo
C:	Clay
D:	Gansler
E:	Gregory
F:	Heberling and Graham
G:	Hicks, Rich, Wertheim and Meyer
H:	Hirsch and Waelchli
I:	Kish
J:	Lesser
K:	Nelson
L:	Price and Valentine
M:	"Rx for Ailing Procurement System"
N:	Sammet and Green
O:	Settlemyer
P:	Snoderly and Acker
Q:	Total Quality Management Master Plan
R:	Weiss
S:	Zairi

Please consult References for complete citation.

important aspects of acquisition and program management.

Because the highest correlation was 47 percent, the degree of significance was calculated by using 47 percent as the maximum. Factors with correlations between 32 percent and 47 percent were considered to be the most significant. Factors with correlations between 17 percent and 31 percent were judged moderately significant. Factors with less than 17 percent correlation were considered to be least significant.

Discussion

Elements of program success were identified by surveying DoD program managers. A factor analysis was performed using relevant literature. Those factors with the highest correlation between survey and literature content were identified as those contributing to program success. This two-step method provides a means of cross-checking survey results with current literature works and focusing on factors that are considered important to program success by both.

The most significant elements contributing to program success, as identified in

the factor analysis of the literature, fall into two categories. The first is acquisition factors, which consist of:

- well-defined requirements;
- the acquisition strategy;
- a program product that works well when fielded; and
- stability in the program.

The second category we define as resource factors:

- quality people;
- program manager responsibility and authority;
- total team concept; and
- program manager skills.

These factors also ranked high in the survey of program managers. This high degree of correlation with the survey adds validity to MacFarland's analysis technique. From these results comes the following list of factors that contribute to program success.

Well-Defined Requirements

A requirement is a formal description of a desired operational capability. Product stability depends on realistic requirements and minimizing changes. As Baumgartner, Brown, and Kelley (1984) state, systems that have problems are usually those that have many changes during design and production, especially changes driven by the user. Thus users should take care to avoid overstated requirements that delay production and lead to higher costs. And producers must carefully coordinate with the users to ensure that the requirements are understood and well defined.

Hicks, Rich, Wertheim, and Meyer (1991) believe that not enough time and attention are paid to successful programs that could serve as possible models for the future. They note that the GAO, which seldom compliments the defense acquisition process, identified the Navy's Fleet Ballistic Missile program as one such highly successful program spanning 15 years. The GAO identified open dialogue between the program manager and the prime contractor and continuous communications with the ultimate users as reasons for this success.

Aquisition Strategy

Like any business strategy or strategic plan, the acquisition strategy is situation and resource dependent. The program manager should examine the internal and external environment to gauge resources and support available. The acquisition strategy should be crafted to help further the program objectives, while meeting constraints placed upon the program by external regulators and regulations.

"Like any business strategy or strategic plan, the acquisition strategy is situation and resource dependent."

Snoderly and Acker (1981) cite one strategy used to reduce acquisition time and costs. The Defense Support Program, which produces ballistic missile early warning satellites, had a requirement to purchase four satellites from their sole-source contractor, TRW, over a five-year period. Normally, the four satellites would

be separately funded, purchased individually, and programmed for delivery in succeeding years. Parts and material purchases for each satellite would be made separately. Administrative costs and potential part obsolescence costs would also be high. Assembly and test production gaps would be created due to uneven production and funding.

The acquisition strategy actually pursued offered cost savings of $134 million for the procurement. The program office acquired parts for all four satellites at one time, in more economic quantities. A single qualification test for all four satellites, because of continuity of design and production, also contributed to efficiency. The above efforts resulted in delivery of the last satellite one year early, saving program administration costs. The acquisition strategy was approved because the program was well established, with validated requirements and little chance of change or cancellation.

"Just as it is difficult to hit a moving target, it is difficult to manage a program that lacks stability."

Works Well When Fielded

The ultimate test and determinant of the success of a program is if the item procured works well in the environment and achieves its mission. Delays in procurement or cost overruns are temporary problems that must be managed in order to keep the program alive. Those problems are forgotten once the system is fielded. The main concern of the ultimate user is if the system works well when deployed.

Stability

Just as it is difficult to hit a moving target, it is difficult to manage a program that lacks stability. Changes in requirements, budgets, and resources make program planning and execution difficult. The program manager must act to maintain stability where possible and manage change where stability is not possible. The program manager, as the prime program advocate, must act to lay the groundwork for external support that will help maintain stability.

Clay (1990) believes that instability is at the core of most defense acquisition problems. He suggests five conditions for creating stability:

- Managers should set out a few key system objectives, consistent with strategies and user needs that are correctly identified and held constant.
- Realistic cost, schedule, and performance estimates must be set. He defines "realistic" as the probability of overperformance being equal to the probability of underperformance.
- Trained and experienced personnel must be assigned to the program who can to achieve the program objectives.
- Resources approved and promised during the planning phase must be provided, unless the program fails to achieve its objectives.
- Commitments to complete acquisition tasks must be fulfilled.

Hirsch and Waelchli (1989) equate program stability with quality expert W. Edwards Demming's "constancy of

purpose" and state that it has long been recognized as perhaps the single most important contributor to efficiency and effectiveness in acquisition. Often external factors that the program manager has little or no control over affect program stability. As the program's top advocate, the program manager can still demonstrate constancy of purpose even in these situations.

Quality People

Well-educated and trained people are essential to the success of a program. A reasonable amount of personnel stability and continuity is desirable. Successful program managers hire or develop a talented workforce, mold them into a cohesive team, and motivate them to help further program objectives.

Program Manager Responsibility and Authority

The program manager is responsible for the success or failure of the program, yet there are many factors beyond his control. The solution is for the program manager to assume the authority commensurate with the responsibility for ensuring program success. Baumgartner et al. (1984) quote one program manager as stating, "Any program manager has as much authority as he is willing to step up and take."

Total Team Concept

The program manager should create a program office team atmosphere where everyone must work toward program goals and aggressively manage the program. This team spirit promotes unity of purpose and creates a corporate culture that unifies the program office. Formation of integrated product teams that include the user and contractor serve to foster communication and a joint approach to identifying and solving problems. Although total quality management did not rank as a success factor, the total team concept is one element of a total quality management program that has been identified as contributing to the success of a program.

Program Manager Skills

The ability and skills of the program manager can make or break a program. A combination of leadership ability, communication skills, operational background, and education is important. The program manager must be able to garner support for the program at higher levels, motivate the team, and navigate the program toward successful achievement of its goals. The program manager—as the program's leader and manager—is in charge. Price and Valentine (1992) recommend results-oriented program management as an effective way for program managers to mold organizational culture, emphasize long-term goals and quality, and focus on the big picture. Results-oriented program managers have a sense of ownership in the program, believe in the mission, and communicate this to the program team. They create an environment focused on excellence and successful program completion.

"The ability and skills of the program manager can make or break a program."

Baumgartner et al. (1984) consider the ability of the program manager to be a vital element in the success of a program. Successful programs have managers who

have the ability to communicate well with all types of audiences, are clearly in charge, take authority needed to perform the job, and hire quality people. The authors state that one important program manager skill is dealing with the external environment. They recount how when one program manager was required to do something he disagreed with, he would explain what the repercussions of that action would be. If the person persisted, the program manager explained that he would tie that person's name to the required change and its related cost, and schedule impacts so that everyone in the program's chain of command would know who was behind that change. The person usually acquiesced. As one program manager observed, many people in the Pentagon can say no, creating problems for your program, but do not have the authority to say yes. A program manager needs the skills and understanding to deal with the existing acquisition system and bureaucracy, and the ability to adapt to changes in the system.

RECOMMENDATION

The factors contributing to program success that we've provided here give program managers points of reference, which they should evaluate for inclusion in their programs. These factors are widely recognized as contributing to program success by their peers and by the current literature on acquisition. While all these recommendations may not apply to any particular program, they provide an array of strategies that a manager can implement and monitor to gauge their success.

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APPENDIX A
ACQUISITION PRACTICES SURVEY

1. Please rank the following measures of program success in order of their importance:

   _____ Meets initial operational capability date
   _____ Meets technical performance objectives
   _____ Meets logistics supportability objectives
   _____ Works well when fielded
   _____ Meets cost objectives

2. Please list the factors you believe contribute to the success of a program or are indicative of program success:

3. Has the success of your program been helped or hindered by influences outside the program office such as:

Helped	Hindered	
_______	________	The user
_______	________	Acquisition support agencies
_______	________	Higher command headquarters
_______	________	Congress
_______	________	General Accounting Office

4. Please rate the importance of the following factors to program success using this scale:

Not very important	1
Somewhat important	2
Important	3
Very important	4
Critical	5

A.	Type and quality of people associated with program	1	2	3	4	5
B.	Product requirements and design stability	1	2	3	4	5
C.	Funding stability	1	2	3	4	5
D.	Program manager's technical ability	1	2	3	4	5
E.	Program manager continuity	1	2	3	4	5
F.	Program personnel continuity	1	2	3	4	5
G.	Program's acquisition strategy	1	2	3	4	5
H.	Resources: People, facilities, money	1	2	3	4	5
I.	High degree of technical difficulty	1	2	3	4	5
J.	Low degree of technical difficulty	1	2	3	4	5
K.	Program manager's ability to communicate	1	2	3	4	5
L.	Program manager's ability to lead	1	2	3	4	5
M.	Program manager's field experience	1	2	3	4	5
N.	Program manager's acquisition experience	1	2	3	4	5
O.	Total Quality Management program	1	2	3	4	5
P.	Good relationship with the prime contractor	1	2	3	4	5
Q.	Good relationship with the user organization	1	2	3	4	5

5. Please note any comments you have regarding successful acquisition management practices or this survey.

INTEGRATING COST, EFFECTIVENESS, AND STABILITY

Dr. James P. Ignizio

Various approaches, ranging from conventional cost-effectiveness ratios to newer multiple objective/multiple criteria models, have been used in an attempt to systematically factor cost and effectiveness into acquisition decisions. While this is laudable, we believe that one point has been overlooked: the critical nature of the inherent stability of the system to be developed and/or acquired. We often hear about cost overruns; but what we may not realize is that the underlying cause of such overruns may be something as simple as forgetting to consider the stability of the system. In this paper we attempt to indicate the nature and impact of stability in cost-effectiveness studies—and to propose topics for further investigation.

Whether funding an entirely new system (e.g., an air defense system) or including a new component into an existing system (e.g., inclusion of a new class of helicopter into a rapid deployment system), the goal is the same—procure a system that provides the "biggest bang per buck." To accomplish this, we generally seek a solution that minimizes cost yet achieves certain target levels for a variety of multiple measures of system performance (e.g., range, accuracy, reliability, weight, volume, survivability, availability). Rarely, if ever, does one see the inclusion of system stability as a measure of system performance. And this may explain why program managers discover that their system has unexpectedly experienced a significant cost overrun—as a consequence of its inherent instability.

Before proceeding further, let us define the notion of stability itself. First, stability analysis is not the same thing as sensitivity analysis, risk analysis, or reliability analysis. Conventional sensitivity analysis, risk analysis, or reliability analysis can be effective for dealing with systems of limited size and complexity, if sufficient data (e.g., probabilities of component failure) exists to support the needs of the analysis. However, in many of the real world systems under consideration today, problem size, system complexity and inherent errors (or gaps) in data invariably exist. Furthermore, these conventional methods merely estimate the likelihood of the failure (or degradation) for a given

system. As such, they result in estimates of such things as MTBF (mean time between failures), or the probability of a particular failure mode, or the impact of the variation of a given parameter on the performance of a system.

Stability analysis, on the other hand, addresses the topic of the "likely worst case performance" of a system—normally a system too large, complex, or messy (i.e., the typical real world system) to be dealt with effectively by more conventional means. Extensive experience (e.g., within the aerospace sector, the military sector, and even the financial sector) has shown that a system having a high degree of reliability can and often will fail as an unforeseen consequence of the failure of a certain combination of components. Usually, the only way to evaluate such potentially catastrophic consequences beforehand would be to run a brute force evaluation of all possible combinations of failures. For any real world system, such a process would take years, if not centuries, on even our most powerful computers.

As such, one can think of stability analysis as a systematic attempt to examine the likely worst-case performance of a complex system. In other words, it is an attempt to account for the consequences of "Murphy's Third Law: Anything that can go wrong will." In the following example, the consequences of limiting the analysis of a system to just conventional performance measures is described—and this may be contrasted to the results actually exhibited once a prototype of that system was actually constructed and tested.

Some years ago a contractor for the Navy was tasked with the job of developing an acoustic array for torpedoes. After carefully determining the various measures of effectiveness (e.g., range, sensitivity, sidelobe suppression, etc.) and the cost elements, the contractor—aided by a group of academicians—tried to determine the "optimal" system, in terms of cost-effectiveness. They constructed a mathematical model of the system and then computed, by means of mathematical optimization tools, the solution: the precise amplitude and phase of the acoustic energy to be delivered to each transducer in the array—accurate to the fifth decimal point.

The design team went further in their analysis than is typical; performing a laborious sensitivity analysis of the array as a function of changes in the amplitudes and phases fed each array element. Since the mathematical model was nonlinear, and since the number of array elements were in the hundreds, they could—of course—only examine a finite and relatively limited number of combinations of perturbations in amplitude and phase.

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On paper the solution looked fabulous. Tthe laboratory consisted of a water tunnel in which the array could be tested in what were close to actual conditions. The results for the prototype array that had been fabricated for testing weren't nearly so good. In fact, they were awful. The problem? A slight change in some combination of seemingly insignificant changes in two or more attributes could result in a significant degradation of the array's performance. If this array design were actually deployed, it would require the development of either super-sensitive receivers or a major breakthrough in manufacturing fabrication tolerances. Either alternative would add literally millions of dollars to the cost of the total system (translation: a cost overrun).

Our experience, over three decades of system design and cost-effectiveness analysis, indicates that systems designed to be "optimal" are surprisingly often more likely to be unstable than systems that are more conservative (i.e., less "effective") in design—at least on paper.

"Optimal" acquisition decisions, no matter how cost-effective in the conventional sense, may not be a "good thing."

Graphical Illustrations of Instability

The reason system stability is so important, and why it is so easily overlooked, may be explained graphically. Consider a very simple problem in which the performance of a system is a (nonlinear) function of a single variable. The output of this system, as a function of some variable x, is depicted in Figure 1. The possible values of x range from 0.00 to 0.20. The system performance has two main peaks. The highest is centered at about 0.02 while another peak (somewhat lower but much broader) is centered at about 0.16.

Conventional methods of analysis are optimal seeking. As such, they would determine that the optimal value of x is found at $x = 0.02$ (for a performance value—shown on the vertical axis—of 9 units). However, should the performance function be off as little as 0.01 units (i.e., imagine a horizontal shift in the nonlinear function some 0.01 units to the left or right), the system performance drops from 9 units to 0.1 units—a fall of roughly 99 percent!

Yet, had we selected a less than optimal solution, at $x = 0.16$, the performance of the system would only vary between 8.4 and 8.5 units. In fact, for a solution at $x = 0.16$, the performance function could shift by 0.02 units (twice that which virtually destroyed the "optimal" system), and still result in a performance level between 8 and 8.5 units.

"Our experience... indicates that systems that are designed to be "optimal" are surprisingly often more likely to be unstable than systems that are more conservative (i.e., less "effective") in design—at least on paper."

In a problem this simple, conventional sensitivity analysis (e.g., perturbations of variables and, possibly, the mapping of the response surface) would likely suffice. However, for larger, more realistic problems (i.e., those having numerous variables and in which we have little or no idea as to the shape of the functions involved), such an approach might not be practical.

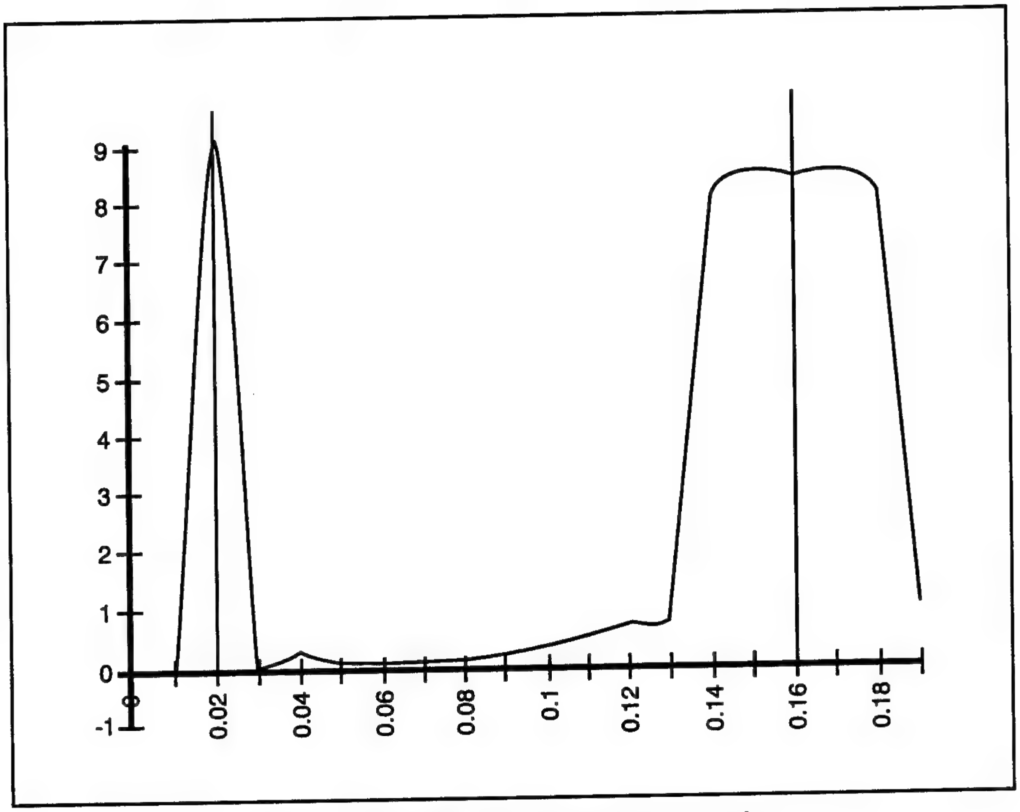

Figure 1. Nonlinear Response Function

In the next section we present a brief overview of existing methods for stability analysis. In the section following that, a proposal for an unconventional approach to stability is presented.

INCLUDING STABILITY IN COST-EFFECTIVENESS ANALYSIS

Some would claim that all one has to do to consider system stability is to perform a sensitivity analysis on the model. The problem with this assumption is two-fold. First, conventional sensitivity analyses are intended, for the most part, for strictly linear, continuous, problems—and the systems that are to be considered for real world procurement or development are invariably (highly) nonlinear. More specifically, they are problems of combinatorial complexity. Second, even if the problem is linear (or a linear approximation seems reasonable), sensitivity analysis is not the same thing as stability analysis.

Sensitivity analysis tells us only the range over which some solution remains optimal (e.g., changes in the basis of linear programming models), or that range of model coefficient values over which the solution still satisfies all constraints (Ignizio and Cavalier, 1994). That type of information, in itself, tells us little about the inherent stability of a given solution.

Other analysts have suggested that we "simply include solution stability" as another objective or constraint—that is, as yet another measure of effectiveness. That would be fine if we could determine a way in which to capture solution stability as a mathematical function; but there is no effective way of doing this.

Others would argue that we use "perturbation analysis." In perturbation analysis we perturb the values of various variables and coefficients in a model, singly and in combination, and observe the effect (Fiacco and Ishizuka, 1990; Perlis and Ignizio, 1980).

For relatively small problems this may provide satisfactory results. But for problems more typical of those faced in the real world, the amount of effort required would be truly enormous. Consider, for example, just a modestly sized problem involving 10 constraint functions, 5 objective (measure of performance) functions, and 20 decision variables (e.g., the value for each of 20 rapid deployment force weapon types). In this problem there would be some 310 model coefficients and right-hand side values. If we restricted our perturbation analysis to just the evaluation of changes in each coefficient and each pair of coefficients, we would be required to perform nearly 48,000 evaluations—each of which would require a large number of sub-evaluations (e.g., analysis of the increments in change of each coefficient or pair of coefficients). Even then we will have ignored those combinations taken three or more at a time. As such, even this modest problem could not be adequately analyzed by means of perturbation analysis.

Stability Analysis Via Genetic Algorithms

If conventional methods cannot assist us in an evaluation of stability analysis, then unconventional approaches should be considered. Recall the acoustic array design problem discussed in an earlier section. The "optimal" design was unstable—too unstable to even consider. However, a "less-than-optimal" design achieved the desired stability without an excessive degradation in the performance measures that were promised, on paper, by the optimal system.

Less-than-optimal conservative designs would appear to have a greater likelihood of remaining stable. Instead of being located on boundaries of the solution space, or at the extreme points of that space, they tend to be found in the interior of the space, and are thus dominated, or inefficient. Consequently, any changes in the system, or any errors in the data should have less impact on these solutions.

"If conventional methods cannot be relied upon to assist us in an evaluation of stability analysis, then unconventional approaches should, we believe, be considered."

A preliminary exploration of an "evolutionary" approach to stability analysis provides a practical means to systematically analyze both the effectiveness and the stability of a solution. In this approach either genetic or evolutionary programming is employed to produce a population of final solutions.

Genetic algorithms (GA) pursue a "survival of the fittest" search for optimality

(Davis, 1991; Ignizio and Cavalier, 1994; Zalzala and Fleming, 1997). Typically, they utilize a Boolean coding of the solution variables—and the result is termed a "chromosome." Evolutionary programming is essentially the same thing, but uses real numbers in coding. For example, the chromosome $x = (1\ 0\ 1\ 1\ 0\ 0)$ may mean that we fund project 1, 3, and 4—and do not fund projects 2, 5, and 6. We see then that a "1" in the x-vector indicates that the associated project is funded, while a "0" signifies an unfunded effort.

Rather than starting from a single solution point and conducting an iterative search, and then moving in the direction of local optimality, genetic or evolutionary programming begins with a population of solutions (tens, or even hundreds per "generation"). These are evaluated for their "fitness" (i.e., the corresponding objective function, or functions are evaluated) and the "fittest" of the bunch are considered for "mating" and "reproduction." Choices are made stochastically, with preference given to the most fit. Mated pairs may reproduce, via an exchange of "chromosomes." However, since reproduction is also stochastic, not all mated pairs will reproduce. Yet another stochastic element is introduced in the reproduction process; some chromosomes may be mutated. These operations result in the population of the next generation. And the procedure continues until some termination criterion is reached. The references provide further information on these notions. However, a detailed understanding of GA is not needed to appreciate the proposed procedure.

"Inherently unstable solutions de-evolve (the reverse of evolution) to poor solutions faster than stable solutions."

While global optimality cannot be guaranteed, genetic and evolutionary algorithms are effective in finding "very good" solutions. In addition, the approach is inherently parallel, and thus computational effort is minimized.

Our proposal is simple and straightforward. Use a genetic or evolutionary programming algorithm to solve the problem under consideration. During the processing of the algorithm, maintain a file of the top 10 or 20 solutions generated by the algorithm. At convergence, proceed to examine this list of solutions for stability.

The question that remains, of course, is just how to evaluate—in a practical manner—the stability of a given solution. Our approach is based upon the following hypothesis: Inherently unstable solutions de-evolve (the reverse of evolution) to poor solutions faster than stable solutions.

Furthermore, if a genetic algorithm is effective in evolving a population of solutions toward a high level of fitness, it would seem reasonable to believe that it would be equally effective in de-evolving optimal or near-optimal solutions to those that are of poor quality. In other words, we will use the GA on good solutions in an attempt to see how long (how many generations) it takes to de-evolve.

The approach that we are investigating may be summarized via the following steps:

- *Step 1:* Model the problem under consideration in a format compatible with GA (e.g., code the solution representation, determine crossover, mutation, and reproduction operators, and pro-

vide a means for the evaluation of the fitness of each solution).

- *Step 2:* Use a GA to solve the problem; maintain a list of the 10 or 20 best solutions generated by the GA.

- *Step 3:* For each of the solutions in the list of the 10 or so best solutions, develop a cluster of solutions about that point by means of perturbation.

- *Step 4:* For each of the clusters in Step 3, use a GA to search for the least fit solution; and record the number of generations required to de-evolve to a sufficiently poor solution.

- *Step 5:* Solutions (i.e., the original solutions used to develop the clusters of Step 3) that de-evolve the slowest are assumed to be the most stable. Those that de-evolve fastest are assumed to be least stable.

We should elaborate further on Steps 3 and 4. In Step 3 we generate a tight cluster, about each point, by means of random perturbation of the coordinates of that point—where each perturbation is held to a small size. In Step 4 we could easily de-evolve to a poor solution by moving across a constraint into an infeasible region. However, the GA should be set so as to disallow such moves (e.g., assign any infeasible point some very high value). In this way the de-evolution takes place entirely within the (assumed) solution space.

Our next step is to perform small perturbations about each of these solutions so as to develop a "population" of solutions all in close proximity to the original solution point.

Following the development of the clusters we would use a GA, on one cluster at a time, to generate poor solutions. Our interest is centered about the number of generations required to de-evolve to some predetermined level representing a poor solution. Those clusters taking longest (i.e., in terms of number of generations) to reach that level are assumed to be the most stable. For example, if it took 50 generations for the cluster about one particular solution (X) to de-evolve, and only 10 for that about another (Y), the first solution (i.e., X) would be considered a far more stable solution.

"Our next step is to perform small perturbations about each of these solutions so as to develop a "population" of solutions (all in close proximity to the original solution point)."

How well does this approach work? The only proper way to evaluate the method is to apply it to real world problems with real world data. Obviously, that is time-consuming. Thus far, we have used the approach on a handful of actual problems and found the results, in each instance, to be very useful in predicting solution stability.

Illustration

To illustrate the concept, consider a more tangible example: the procurement of an air defense system. Such a system is composed of a variety of subsystems and components, and its actual design is a problem of combinatorics. These consist of such things as the choices of missiles,

missile warheads, radar types, support vehicle types, and so on. Typically, the number of possible combinations is massive.

A genetic algorithm is a highly effective approach to problems of combinatorics. As such, we could use such an algorithm to generate not just the "best solution," but also a list of the top 10, 20, or so best solutions (i.e., combinations of subsystems and components forming the air defense system). We performed such an analysis for the design of a number of possible air defense systems, each differing according to the combination of subsystems and components that make up the system. Using simulation, we then determined the top 10 candidates (according to their effectiveness to cost ratios), as listed in Table 1.

Our next step was to form tight clusters about each candidate solution. This was achieved by perturbing each solution ever so slightly: that is, exchange one or two components in the present solution for components not in solution. This exchange is repeated until we have a population of solutions (i.e., clusters) centered about each candidate solution.

We then apply a GA to each of the clusters (one at a time) and record the number of generations needed to de-evolve. The cluster taking the longest is considered the most stable population, and the original solution from which that cluster was generated is selected as the most stable solution.

What we discovered was that candidate system A may have had the "optimal" effectiveness to cost ratio, but it was extremely unstable. Candidate system F, on the other hand was, far and away, the most stable of the 10 prototype air defense systems. While its effectiveness to cost ratio may be somewhat lower than that of A, it likely makes up for that deficiency in terms of its superior stability. After all, would the military prefer an air defense system that is optimal on paper, yet whose performance can radically be degraded by the chance combination of failures for a number of components?

Table 1: Candidate Air Defense Systems

Candidate	Cost	Effectiveness	Effectiveness/ Cost Ratio
A	50	80.00	1.6
B	48	76.32	1.59
C	52	84.42	1.585
D	54	84.78	1.57
E	49	76.44	1.56
F	53	81.62	1.54
G	56	84.00	1.5
H	57	79.80	1.4
I	56	67.20	1.2
J	59	64.90	1.1

Summary

In this paper we have explored the notion that cost-effectiveness analyses, in support of the acquisition process, may be ignoring an extremely important, if not critical factor: the inherent stability of the system. In such problems, stability may be far more important than such conventional, and comfortable, notions as optimality (i.e., the "best" cost-effectiveness). Yet, while debate rages as to what tool or tools are needed to develop optimal designs, relatively little attention is paid to the stability of solutions in what will always be imperfect mathematical models.

We propose that consideration be given to the concept of considering solution stability by means of evolutionary algorithms. While our hypothesis (i.e., that inherently unstable solutions de-evolve to poor solutions much faster than inherently stable results) has only been explored at a preliminary level, the results thus far seem to support the thesis. Hopefully, this paper will encourage further efforts in this area.

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SUMMARY RESEARCH REPORT ON CRITICAL SUCCESS FACTORS IN FEDERAL GOVERNMENT PROGRAM MANAGEMENT

James H. Dobbins and Richard G. Donnelly, Ph.D.

This pilot study identifies critical success factors common to government acquisition programs. It demonstrates that how these factors are identified and used, how they are measured, and how they are influenced should be a mandatory component of education for every federal government program manager or program manager selectee.

An objective of program management, and of program management education, is repeatable success as a program manager. It does little good if managers are considered successful but do not know why they were successful and do not know how to repeat their successes. Success that is the result of luck is not really success.

The use of critical success factors (CSFs) in the management of corporations has been the subject of several published studies. The research we describe here investigated CSFs as they apply to acquisition programs within the Department of Defense (DoD). The use of CSFs in the development of critical management information systems for the DoD program manager would have significant benefit.

Although profit-driven private sector companies have virtual autonomy in their selection of suppliers and partners, researchers investigating CSFs had largely ignored federal government projects at the time this study was done. Since then, a few federal agencies have reported CSFs for their organizations, but none of the reports published have indicated how the data was captured or validated, nor have they provided a CSF-based measurement process. The activity in this area within the federal departments therefore seems to be at a fairly preliminary stage of development.

The questions we sought to answer in this pilot study are:

- Are there any general CSFs for DoD programs?

- Are there any CSF-related measures, quantitative or qualitative, that can be used on DoD acquisition programs?

- Are there any significant differences in the CSF data between weapon systems and automated information systems (AIS)?

The Initial Research Environment

The importance of CSFs in management first gained widespread attention following publication of an article by J. F. Rockart (1979). It showed the need among top executives for certain critical elements of information, notg provided by the management information systems (MIS) or the data analysis systems available. Rockart defined CSFs as:

> ...the limited number of areas in which results, if they are satisfactory, will ensure successful competitive performance for the organization. They are the few key areas where things must go right for the business to flourish. If results in these areas are not adequate, the organization's efforts for the period will be less than desired.

He further described them as "areas of activity that should receive constant and careful attention from management."

Rockart showed that executives suffered from data overload, but were starved for the right kind of data essential to making the decisions necessary to manage their enterprises effectively. This includes the identification of CSFs as well as the establishment of indicators that can alert the executive when a CSF is changing or when the assumption upon which a CSF is based is no longer valid.

The initial Rockart paper was closely followed by the publication of a methodology for CSF identification developed by Bullen and Rockart (1981). The research conducted since then has been done either through the interview process as described by Bullen and Rockart, or by the questionnaire method.

Critical Success Factors

Identifying and managing CSFs, and tracking them separately from the ever-increasing amount of data to which executives are subjected, has been the focus of significant private sector research. Some of the research has limited the study to those activities over which the program manager has direct control (Cleland and King, 1988); the majority of researchers

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have broadened the focus to include elements beyond the direct control of a project manager, but still within the sphere of things that either he could manage, or that could exert significant influence on his activities.

Bullen (Bullen and Rockart, 1981) has suggested that CSF identification be focused on whether CSFs fall into one or more of several key areas. These key areas, plus one (modification management) we have added, are:

- Global or industry related: These are activities essential to project success that would be true of any project or company operating in the particular environment (industry or business area).

- External influences: These CSFs are governed by external factors that can significantly influence the success of your endeavor.

- Internal influences: These are determined by internal factors that can significantly influence project success.

- Current and future: Included here are time-driven CSFs that are essential to project success. Current CSFs are activities that must be done in the near future. Future CSFs are those which are long range. Planning for the success of future CSFs may be an activity that requires immediate attention.

- Temporal and enduring: These are significant influences that either have a short-term duration or are present through most or all of a project.

- Risk abatement: Some activities are necessary in order to avoid significant identified risks to project success.

- Performance: These are identifiable levels of performance or achievement that must be realized for the project to be successful.

- Special monitoring: These activities or events require special monitoring, protection, or contingency planning in order to assure project success.

- Quality: Quality requirements, if not met, will mean the failure of the project.

- Modification management: Some activities or conditions that currently exist or are currently planned will, if not changed, cause the project to fail.

Review of the Literature

Most research has been focused on the identification of CSFs for executive level managers in specific industries, or heads of specific kinds of departments, principally MIS departments. There has also been some minimal research focused on the diversity of applications of CSFs. One fairly common problem with much of the reported research is that many of the identified CSFs have not been stated in the form of an activity, as was clear in the original group of definitions given by Rockart and noted above. This led to the identification of CSFs that were ambiguous and hard to measure.

One of the early research studies that demonstrated this problem was conducted

by Boynton and Zmud (1984). This research focused on the use of CSF, and showed that CSF analysis can be used successfully to identify key concerns of senior MIS management, can be used in developing strategic plans, and can help identify critical implementation issues. CSFs can also be used to help managers achieve high performance and establish guidelines for monitoring a corporation's activities.

Boynton and Zmud also noted that CSF analysis demonstrated certain weaknesses. They found that CSFs were difficult to use unless analysts possess the capability to successfully apply an identification process. Some analyst or manager bias may be introduced through the interview process, and if used as a requirements analysis methodology the resulting information model may not accurately represent the deployment environment. But the researchers concluded that, despite these criticisms, the CSF method generates user acceptance among senior management, it works well at the policy, operational, and strategic levels of information resource planning. It forms a bridge between corporate strategic interests and information systems (IS) strategic planning.

"This research focused on the use of CSF, and showed that CSF analysis can be used successfully to identify key concerns of senior MIS management, can be used in developing strategic plans, and can help identify critical implementation issues."

Boynton and Zmud (1984) also found that CSFs can help identify issues that merit close management attention, their intended purpose, and they are useful for requirements analysis in building conceptual models of an organization or a manager's role. This may not be appropriate, however, where managers have difficulty conceptualizing. Their data supported the assertions that CSFs generate enthusiasm from senior managers, improve user communications, and build managerial support for information technologies, and that CSFs were particularly successful in defining organizational information infrastructures. Their data also indicated that lower-level managers may have difficulty formulating meaningful CSFs and specific information measures. This finding underscores the need for specific training in CSF identification and analysis processes and the need to describe these factors in terms of activities.

Boynton and Zmud (1984) conclude that the weaknesses attributed to CSFs can be overcome through careful application of the method, while CSF strength as a structured design process for eliciting both MIS plans and managerial information needs is key to its success.

In another significant study, "Variation of Critical Success Factors Over Stages in the Project Life Cycle" (Pinto and Prescott, 1988), the authors hypothesized a set of CSFs, and then conducted a validation study based on empirical evidence. The objective was to identify a set of CSFs for each life cycle phase that were general rather than company- or industry-specific, and to determine the relative importance of the CSFs across life cycle phases. The final set of CSFs were identified and related to the life cycles during which they were important (see Table 1).

Several identified CSFs demonstrate the difficulty of not specifying the factor in terms of an activity. It is difficult to measure, and therefore difficult to know whether an activity has been done well, when it is specified in terms as ambiguous as "technical tasks" or "project mission."

Zahedi (1987) developed an evaluation of reliability of an information system as a measure of the system's success based on CSFs. This research addressed the issue of the difference between behavioral and perceived measures of IS effectiveness resulting from a lack of conceptual foundation to guide proper measurement development, and the absence of a rigorous program of measurement validation. It identified the need to define CSFs and identify how they are interconnected. This was another look at a question similar to that investigated by Pinto and Prescott (1988), but looking at the set of CSFs from a reliability viewpoint. In each case the CSFs were not treated as isolated objects but rather activities that are interrelated.

In "The Multiple Uses of CSFs" (Leidecker and Bruno, 1984), the authors stress the applicability of CSFs for strategic planning and business strategy development, identification of threats and opportunities, and identifying a criteria for strengths and weaknesses assessment.

Walsh and Kanter (1988) stress the importance of using the CSF identification process to identify major causes of project failure and then ranking these major causes by relative value, so that such problems can be avoided in future programs.

One of the few comparative studies done (Chung, 1987) concluded that if the inquirer wants to know what management is, then the process view should be studied. However, if one wants to know why

Table 1.
Importance of Various Critical Success Factors in the Project Life Cycle

Phase	CSF
Concept	Project mission Client consultation
Planning	Project mission Top management support Client acceptance
Execution	Project mission Troubleshooting Well-defined schedule or plan Technical tasks Client consultation
Termination	Project mission Technical tasks Client consultation

selected organizations are successful in highly competitive environments, then one must study the three critical success factors of corporate strategies, human resources, and operational systems. His conclusion is that the truly successful companies deal with these three CSFs differently from the way they are treated in other companies.

More recently, the research has continued with the same commercial emphasis as described above, but applied to current business trends. One group studied critical success factors as they apply to establishing strategic alliances (Rai, Borah, and Ramaprasad, 1996). A further study of CSFs in business alliances, this time with a process focus in the oil and gas industry, was reported in the trade press ("Seven Critical Success Factors," 1996).

"CSF analysis has also been applied directly to people, to measure productivity."

CSF analysis has also been used for community improvement. This is closer to the public sector than most studies, and is an example of the analysis being applied to a fairly narrow focus area (VanDeusen, 1996). The researcher gleaned six factors from 14 community-scale future search conferences conducted between 1993 and 1995. These CSFs are leadership, scope, participation, structure, results, and strong conference management.

Note once again the ambiguity and the problem when CSFs are not specified in terms of activities. It is very difficult to measure something like "structure" or "scope" or even "leadership," especially when something like leadership can be defined and measured in so many different ways.

Business processes for new product development have not escaped the application of CSF analysis. A benchmarking research study of 161 business units (Cooper and Kleinschmidt, 1996) identified the CSFs for new product performance at the business unit level. The researchers found that the CSFs fell into major categories. Two key performance dimensions—profitability and impact—were identified. Four key drivers were identified: a high-quality new product process, the new product strategy for the business unit, resource availability, and research and development spending levels. Merely having a formal new product process had no impact.

CSF analysis has also been applied directly to people, to measure productivity. Christine Bullen, one of the leaders in the application of CSF analysis, completed a research study of knowledge worker productivity (Bullen, 1995). She found that the context-specific nature of personal productivity demands an understanding of the processes by which knowledge workers achieve their goals and objectives. Once the nature of personal productivity is understood, measurement becomes a much simpler task and the measures have real meaning.

These studies all show how CSF analysis is applicable to a wide variety of industries and subsets of industries. CSF analysis has also been effectively applied to individual process areas within a corporation, such as strategic planning and information technology implementation, although it is not routinely found as a part of strategic management.

Research on the application of CSFs to program management, and in particular

military program management, is lacking. Research on evaluating the true criticality of identified CSFs is lacking in any environment, government or private sector. There is an implied assumption in much of the research to date that managers are relatively equal in their ability to identify CSFs that truly are critical to project success.

The Research Method

This research was conducted using the survey questionnaire method. The survey instrument was developed based on the CSF categories identified by Bullen (1995), as noted above, plus the one category added by these researchers. In the instrument, the participants were asked to identify both CSFs according to the indicated categories as well as their recommended associated measures for each CSF. The instrument was mailed to two groups of program managers; those managing embedded system programs and those managing automated information systems. The returns were analyzed and the data captured so that responses could be made to the initial research questions. Data was separated between the two groups of program managers, and the results were examined for each group individually as well as comparatively so that common CSFs and measures could be identified. The findings were evaluated on this basis.

Having selected the survey approach, the set of program managers to whom the questionnaire was sent was obtained from lists maintained by the Information Resources Management College (IRMC) of the National Defense University in Washington, DC, and by the Defense Systems Management College (DSMC) at Ft. Belvoir, VA. Those from the IRMC were program managers for the development of non-weapon systems, and are identified as Group B. Those from the DSMC list were program managers for the development of systems that are identified as embedded systems, typically weapon systems, and identified as Group A.

"Research on the application of CSFs to program management, and in particular military program management, is lacking."

Initial Research Results

CSF Identification

The data received was broken down into two groups. The Group A universe was 73 program managers. There were 20 Group A returns. The Group B universe was 57 program managers (14 returns).

The returns were examined for identification of CSFs and related measures that might be, or are being, used. No one program manager reported more than 10 CSFs. The Group A program managers collectively reported 37 different CSFs. The Group B program managers reported 29 different CSFs. Some reported CSFs, even though they were not stated in exactly the same words, were similar enough in wording that they could be combined. This distillation left us with 18 CSFs common to both groups.

It should be noted that a few other CSFs were identified in addition to those

reported here. These were very specific to the particular program and are therefore not included in this report because this research effort sought to determine if there were CSFs that applied generally within Group A and Group B, and if there were any common to both groups.

MEASURES

The respondents were asked to identify measures they use, or thought they should use, for each CSF they identified. There was no requirement to limit the number of measures for each CSF. The Group A respondents identified 41 different measures.

"The CSF identification data was compiled and ranked by priority."

Each Group A respondent identified a total of at least 6 measures. The Group B respondents identified a total of 29 different measures. Three of the respondents for Group B identified no measures. One other Group B respondent indicated that there were too many factors required to come together for success and the only real measure is the ultimate outcome.

SYSYEM SIZE

Program size was requested in terms of dollar value of the total procurement. The responses received for Group A indicated total program sizes from $45 million to $30 billion. The responses received from Group B indicated program sizes from $400,000 to $3 billion.

DATA ANALYSIS PROCESS

The CSF identification data was compiled and ranked by priority. Each CSF was given a number, and the number of times each was identified was recorded. Those CSFs identified most frequently were ranked highest in priority. This same analysis was done for both Group A and Group B. Those CSFs identified as being common to both Group A and Group B were also ranked in terms of frequency of response.

Measures identified by the respondents are given in a separate chart. The measures reported were also examined for their applicability to the CSF identified. They were also examined in terms of their priority. If a critical success factor was seen as high priority, we judged whether this was reflected in the measures identified for that CSF.

ANALYSIS AND FINDINGS

Table 2 presents the CSFs from the Group A responses. A unique component of the Group A response for CSF Number 4, "technically competent program office staff," is establishing system engineering expertise within the program office. This aspect of technical competency was not present in the Group B responses. Table 3 shows Group B CSFs. Note that "stable and adequate budget" was the most frequently cited factor. Its prominence in comparison to the other factors was not as dramatic as the most prominent CSF in Group A. Of the 18 CSFs common to both lists, there were evident differences in emphasis, both in terms of frequency of reporting between the two groups as well as the subtleties of their content (Table 4).

Table 2. Group A Critical Success Factors in Priority Order

CSF No.	Times	Factor
12	15	Continuous meaningful visibility using measures
4	9	Technically competent program office staff
2	9	Clearly defined and stable requirements, including interface
1	8	Stable and adequate funding
3	5	Risk management
7	5	Schedule management
15	5	Stable, qualified industrial base
17	5	Effective vertical and lateral communications
16	4	Management political influencing agents
6	3	Stable and adequate personnel resources
8	3	Cost management
9	3	User involvement, support, and acceptance
10	3	Strong and structured quality control
11	2	Clearly and objectively defined project goals
19	2	Development and execution of program management strategic plan
22	2	Change management
5	1	Configuration management and control
13	1	Other agency support for training and government-furnished equipment (GFE)
14	1	Adequate program office resources
18	1	Leadership
20	1	Thorough system documentation
21	1	Test and evaluation master plan approval
23	1	Program office teamwork
24	1	Effective and timely decision making
25	1	Foreign military sales
26	1	Measure and control integrated logistics support performance
27	1	Initiation of new projects

Table 3. Group B Critical Success Factors in Priority Order

CSF No.	Times	CSF
1	10	Stable and adequate budget
9	9	User involvement and support
12	9	Effective technical performance evaluation
2	8	Detailed requirements analysis
4	8	Technically competent staff
19	7	Top management support
17	6	Effective lateral and vertical communications
7	6	Schedule management
10	6	Strong quality control program
6	5	Stable project staff
16	5	Management of political influencing agents
13	4	Other agency support: Training and GFE
3	3	Risk management
20	3	Strong knowledge of life cycle management
23	3	Incremental acquisition
8	2	Cost management
22	2	Common sense
11	2	Clearly defined mission
14	2	Adequate program office resources
21	1	Objective economic analysis
18	1	Leadership
15	1	Stable, qualified industrial base
5	1	Configuration management
24	1	On-site team to prevent fraud, waste, and abuse

Overall Observations

Given the publicity generally afforded to configuration management, it was a surprise that this factor was named only once in each group. This could mean that those reporting did not recognize the importance of configuration management, or recognized its importance, but believe it

Table 4. SFs for Groups A and B Combined, in Priority Order

CSF No.	Times	CSF
12	24	Continuous meaningful visibility using measures
1	18	Stable and adequate funding
18	2	Leadership
2	17	Clearly defined and stable requirements, including interface
4	17	Technically competent program office staff
9	12	User involvement, support, acceptance
7	11	Schedule management
17	11	Effective vertical and lateral communications
10	9	Strong and structured quality control
16	9	Management of political influencing agents
3	8	Risk management
6	8	Stable and adequate personnel resources
15	6	Stable, qualified industrial base
13	5	Other agency support for training and GFE
8	5	Cost management
11	4	Clearly and objectively defined project goals
14	3	Adequate program office resources
5	2	Configuration management and control

is done well enough now not to be a prime candidate for program manager attention.

The questionnaire asked the program manager to list activities that were believed to be critical to the success of the program. Issues reported will, in some way, reflect those areas that have required a significant degree of program manager attention.

Another unexpected result was the placement in order of prominence in which risk management appeared in the Group B list, being number 13 in order of frequency of response. This same CSF is ranked number 6 in order of importance in Group A.

With regard to the CSFs common to both groups, the list reflects a strong belief that factor number 12, continuous meaningful visibility using measures, is of primary importance to program success for any system. Stable and adequate funding, clearly defined and stable requirements, and technically competent program

office staff were the factors next in order of importance, and these three are nearly equal in prominence. These four CSFs appeared more prominently than either cost management or schedule management. This may reflect a belief that if these top four CSFs are accomplished, cost management and schedule management are more easily accomplished. This may also suggest that the focus of the external oversight groups—cost and schedule—is not among those activities that are most important to program success, at least not as viewed by those responsible for executing the mission of program management.

One must also recognize that the CSFs identified are not necessarily disjoint. For example, the factor continuous and meaningful visibility will be a necessary component of risk management. This is likewise true of the CSFs strong and structured quality control, and technically competent program office staff. All of these tend to be means for managing program risk.

MEASURES

Analysis of the measures was accomplished in light of the identified CSFs. It was expected that the most frequently mentioned CSFs should have measures reflecting them, and those with minimal mention may be expected to have the least number of measures.

Table 5. Group A Measures in Priority Order

No.	Frequency	Measure
1	10	Stable and adequate budget
5	10	Deviation from schedule
4	8	Deviation from cost
2	7	Number and frequency of requirements changes
6	7	Number of unique trouble reports
3	4	Changes to the budget
8	4	Results of tests of independent systems
20	4	Cost of change versus cost of delay equals cost to improve
9	3	User or contractor walkthroughs and reviews
12	3	Funding level versus plan
7	2	Number of customer complaints
10	2	Prime contractor productivity per 7000.2
16	2	Program plan assessment (qualitative)
21	2	Number of reworks or rewrites

(continued)

Table 5. Group A Measures in Priority Order (continued)

No.	Frequency	Measure
23	2	Time between problem occurrence and problem identification
25	2	Time delay of GFE deliveries
1	1	Quantitative assessment of requirements
11	1	Program quality targets
13	1	VROC, mean time between failures (MTBF), Pd, mean time to repair (MTTR)
14	1	System availability
15	1	Response to change (qualitative)
17	1	Number of issues requiring higher approval
18	1	Time taken for approval decisions
19	1	Number of acquisition protests
22	1	Number of first time approvals
24	1	Time to process approved change
26	1	Workload stability
27	1	Number and effect of Congressional interactions
28	1	Effectiveness of visibility processes
29	1	Number of delay or disruption claims from contractor
30	1	Reject rates
31	1	Number of quality deficiency reports
32	1	RAM measures
33	1	Number of miscues per month (no coordination; misunderstand)
34	1	Number of technical surprises per month
35	1	Number of suggestions adopted by contractor
36	1	Number of delinquent action items—days late
37	1	Cost versus operational effectiveness
38	1	Number of risks identified, month
39	1	Number of risks resolved per month
40	1	Number of qualified staff versus need
41	1	Number of physical resources versus need

In Group A (Table 5), the most frequently mentioned measure is number 5, deviation from schedule. The next most frequently mentioned measure is number 4, deviation from cost. This may be reflective of the ease of data collection, and the need to respond to the program executive officer, the GAO, Congress, and the Defense Acquisition Board, rather than focusing on those activities that the program managers clearly felt were of significantly superior importance to program success.

Given the importance afforded the CSF identified as continuous visibility, a number of measures can be considered reflective of this CSF. They are shown in Table 6. In terms of sheer volume, these measures reflect the importance afforded continuous visibility. However, they were distributed across the spectrum of those reporting, and the majority of the measures were only identified once, an obvious cause for concern. The two most frequently mentioned of all the visibility measures are those related to requirements changes and those related to trouble reports. The next most frequently mentioned measure was number 8, test results.

Walkthroughs and reviews, number 9, a widely publicized source of visibility,

Table 6.
Measures Reflecting the Importance of the CSF Continuous Visibility

No.	Frequency	Measure
2	7	Number and frequency of requirements changes
6	7	Number of unique trouble reports
8	4	Test results
9	3	Walkthroughs and reviews
7	2	Number of customer complaints
10	2	Contractor productivity
1	1	Quantitative assessment of requirements
11	1	Program quality targets
13	1	VROC, MTBF, Pd, MTTR
14	1	System availability
28	1	Effectiveness of visibility process
31	1	Number of quality deficiency reports
32	1	RAM requirements
34	1	Number of technical surprises per month
38	1	Number of risks identified per month
39	1	Number of risks resolved per month

Table 7. Group B Measures, in Priority Order

No.	Frequency	Measure
4	4	Deviation from cost
5	4	Deviation from schedule
6	4	Number of unique trouble reports
10	3	Program reviews
12	3	Product quality
22	3	System throughput (performance)
2	2	Number of system requirements changes
3	2	Budget changes
13	2	Funding level versus plan
16	2	User feedback
20	2	External and internal independent verification and validation
7	2	Number of customer complaints
1	1	Requirements review
8	1	User acceptance
9	1	Test results data reports
11	1	Productivity
14	1	System reliability
15	1	Downtime: Rate and duration
17	1	Progress demonstration
18	1	Contractor product demonstrations
19	1	Personnel evaluations
21	1	Milestone resource review
23	1	System backlog
24	1	Analysis reports
25	1	Evaluation against oversight criteria
26	1	Number of support complaints
27	1	Number of software changes
28	1	Time to complete software change

was only mentioned three times. This is cause for some concern, both because of what walkthroughs and reviews can provide that is not being used, and because of the need to assure that these visibility mechanisms are properly reflected in the acquisition process, particularly in the request for proposal and the contract. For CSF number 4, technically competent program office staff (the second most frequently mentioned CSF), there are virtually no measures reflected.

It is evident that there is a lack of correlation between those activities identified as CSFs for Group A and therefore deemed critical to program success, and the measures used or suggested. The number of measures related to the top priority CSF, but that were only reported once, reflects a lack of consistency among those engaged in acquisition activities in terms of how commonly recognized critical activities can and should be evaluated.

"One clear concern is that if program managers recognize certain activities to be critical to program success, and the program manager's information network does not provide measures reflective of those critical factors, then their ability to manage those factors is jeopardized."

In general for Group B (Table 7), the lack of dominance of any one measure, and the deviation of the three measures deviation from cost, deviation from schedule, and number of unique trouble reports being the most frequently named, may be reflective of a general lack of familiarity with quantitative evaluation processes as well as a lack of consistency among those engaged in non-weapon system acquisition in terms of how those activities deemed critical to success can and should be evaluated.

Although CSF number 2, detailed requirements analysis, is noted eight times, measure number 1, requirements review, was only mentioned once, and measure number 2, number of system requirements changes, was only mentioned twice. A total of 16 of the 28 measures reported were only mentioned once. Six of the measures were only mentioned twice. Therefore, only 6 of the 28 measures were mentioned more than twice, although 11 of the 24 CSFs for Group B were listed at least five times. There is a clear lack of correlation between the activities considered critical to program success and the management information available by which the program managers can measure, evaluate, and make use of those critical factors. The most frequently named measures are more reflective of response to oversight groups than they are of the issues actually considered by the program managers as most critical to program success.

One clear concern is that if program managers recognize certain activities to be critical to program success, and the program manager's information network does not provide measures reflective of those critical factors, then their ability to manage those factors is jeopardized. The information system used by the program office will not be sufficiently supportive of the program needs.

FINDINGS

Based on the above, we can list a number of findings.

- The CSFs for DoD program management are identifiable, and their explicit identification would clearly assist the program managers in maintaining management focus on the factors most important to program success.

- A significant number of CSFs are common to both Group A and Group B types of programs.

- The component assumptions and emphasis for a given CSF common to both Group A and Group B may be slightly different. This difference is largely a function of the difference between the missions of the two groups, Group A being more concerned with the complete development of total systems than is Group B.

- The CSFs identified by the program managers as the most significant for program success are not those factors that receive the most attention from the oversight activities and agencies.

- The measures identified most often by the program managers as those used or recommended are significantly more oriented toward cost and schedule (which must be briefed to the oversight agencies) rather than toward factors identified by the program managers in the field to be most critical to the program success.

- There is no widely recognized and generally used set of measures consistent with the most frequently reported CSFs. This leads to the conclusion that even though various factors are recognized as critical, they are not usually explicitly identified and the information network required to manage against those critical factors is not developed.

- A commonly recognized set of CSFs, and a consistent measurement-based information network based on these CSFs, would be of significant benefit to the program managers as well as the oversight agencies. Such a management system would significantly improve the management success potential on programs across the board, and would provide the external groups a consistent way of evaluating and comparing different programs so that recommendations for future improvements could be intelligently based.

- A CSF-based information network for program management would lend itself to not only increased visibility and awareness for the program manager and staff during all life cycle phases, but would provide the base for the establishment of measures for determining when the underlying assumptions for a given CSF may be changing.

- A CSF-based information network would provide a common framework for productive discussions between the program manager and the external groups, including the development contractors, and would greatly support the effectiveness of IPTs.

- A CSF-based information network would significantly reduce the duplicative reporting and diversions the program managers experience under the present conditions.

- A CSF-based analysis process would be a significant teaching instrument for educating prospective program managers in strategic thinking in terms of those considerations critical to success.

Some Limitations

The survey questionnaire process used for this research project has both strengths and weaknesses. An inherent strength of the questionnaire approach lies in the number of program managers who can be accessed simultaneously, with the resultant savings in time and dollars. It provides a neutral and standardized method of data collection and allows those responding to provide not only the identification of CSFs, but also a view of the assumptions underlying the CSFs and the ways in which they can be measured.

"An inherent strength of the questionnaire approach lies in the number of program managers who can be accessed simultaneously, with the resultant savings in time and dollars."

One of the weaknesses of this process is the lack of opportunity to discuss a question with the program manager and draw out responses that fully consider the question and its implications. This can be very important when seeking responses from managers with regard to a concept or process they are not already familiar with. It is subject to a certain degree of bias on the part of those responding and does not allow for pursuit of additional issues that might be important to the result and which might not be explored without the aid of a skilled interviewer. In addition, there is no protection from the tendency to either not respond at all, to have a subordinate provide the responses, or to respond hastily without giving the matter the intellectual time it requires.

Recommendations

Based on the information provided above, we recommend the following.

- Educate program managers and their staff in the CSF identification process. The failure to explicitly identify CSFs for a program will invariably result in the continued focus on cost and schedule after they become problems, will inhibit the development and use of effective life cycle measures, and will prevent the development of a truly effective program management information system. Cost and schedule problems are generally effects, not causes. They are the results of conditions that should be identified and managed much earlier than the time when a cost and schedule variance first appears.

- Educate the oversight agencies in the CSF identification process and the importance of this to their management functions.

- Educate the program managers and their staff in development of information networks consistent with the critical success factors.

- Establish oversight reporting mechanisms consistent with critical success factors so that critical information is reported when it is needed.

Continuing Research

Research is currently being conducted using an interview process. The results will reflect whether there are any changes to the CSFs reported by program managers that may result from acquisition reform policy initiatives. Continued research is also being conducted to produce a model for evaluation of actual criticality of reported CSFs. It is anticipated that the development of this model will provide a means to alleviate the need to assume that all managers are equally skilled in their ability to identify CSFs and engage in effective strategic thinking.

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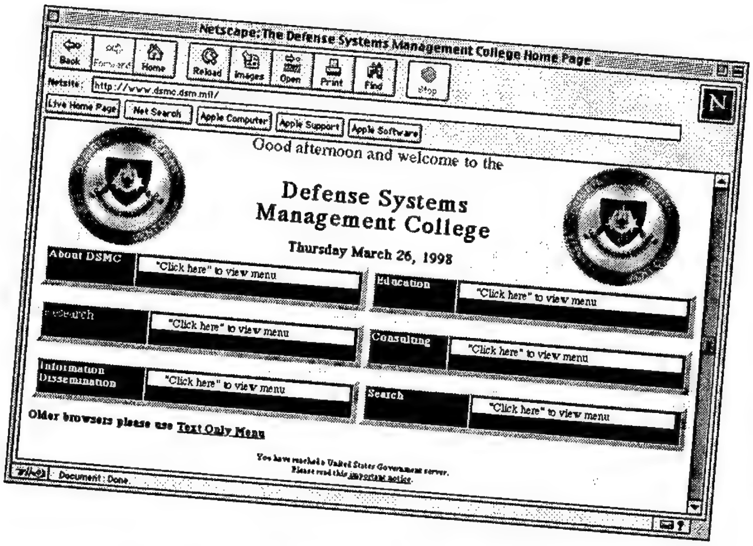

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